Accompaning appendix containing tactual maps available on interlibrgry loan fpom University of Warwick Library

Design, Production and Evaluation of Tactual Maps for the Blind.

J.M.Gill

A thesis submitted for the degree of Doctor of Philosophy in the Department of Engineering, University of Warwick.

1973

Appendix 7: Tactual maps not sent.

PAGE

NUMBERING

AS ORIGINAL

Abstract

A computer-assisted system has been developed for the production of tactual mobility and orientation maps for the blind. The system involves using computer-aided design techniques to generate the input for a computer-controlled machine tool. Plastic copies are vacuum formed from an epoxy resin master. The main advantages of this system are quality, versatility and speed.

Experimental studies have been undertaken on the tactual discriminability of areal, line and point symbols produced by this system. A further experiment studied the retention of meanings associated with fourteen tactual symbols and the ability of blind schoolchildren to locate these symbols on a map.

A pilot study has been carried out on the acceptability of four design parameters:

(i) Double and single representation of roads.

(ii) Choice of plastic.

(iii) Symbol elevation.

(iv) Methods for marking road names.

A number of tactual maps have been made for informal evaluation by a larger section of the blind community.

As a result of this work a system has been evolved which can support further research in the general area of tactual representations, and which can also form the basis for a

production unit to meet some of the demands for this type of aid. It has proven possible to identify sets of symbols which may prove useful to the future design of these maps.

Contents

Acknowledgments

The basic system for the production of tactual graphical representations was submitted for the degree of Master of Science at University of Warwick in September 1971. The work described in Appendices 6.2, 6.3 and 6.4 was done jointly with G.A.James of the Blind Mobility Research Unit. The experimental materials were made by the author, the testing was done jointly and the papers were written by the senior author.

I would like to thank my supervisor Professor J.L.Douce and Dr L.L.Clark (American Foundation for the Blind) for their considerable help and encouragement with this research, and the Medical Research Council for their support of this research programme.

1. Introduction

Embossed maps of towns or buildings can be a useful aid to part of the visually handicapped population. Since there was no existing system for the economic production of high quality embossed maps in small quantities, the first aim was to develop a system to meet this specification.

The design of these maps was studied in cooperation with G.A.James. Experiments were undertaken to identify sets of discriminable areal, line and point symbols. A further experiment studied the retention of meanings associated with the embossed symbols and the ability of subjects to locate these symbols on a map. These experiments resulted in the identification of some of the significant parameters in the design of a tactual map.

Graphical representations are an established mode of communication for the sighted, but the visually handicapped have tended to rely on other forms of representation such as verbal or written descriptions. Such descriptions have obvious limitations for conveying information about complex spatial relationships.

The earliest reported method of producing embossed material was in 1517 by Francesco Lucas who engraved alphanumerics in wooden blocks. The first single-copy tactual maps were probably made by Weissenbourg in the early 18th centruy by sewing beads and threads on linen. In 1785 Valentin Hauy successfully embossed raised images in paper, but it was not until the last decade that maps have become widely available to the blind population. Leonard (1967) demonstrated that tactual maps can be a useful aid to mobility but no estimate has yet been made of the number of potential users.

The main problems in designing a tactual mobility map are:

(i) Identification of useful landmarks.

(ii) Coding the information in an embossed notation.

(iii) Manufacture.

(iv) Training the user in the reading and interpretation of the map.

The identification of useful landmarks is not a trivial task since they may be dependent on the type of mobility aid used; for instance guide dogs are trained to avoid obstacles such as pillar boxes. A landmark should have a known and exact location so auditory and olfactory cues can sometimes be used. A further factor is that useful landmarks for the partially-sighted differ considerably from those used by the blind, but no research has yet been done on this problem.

Franks and Nolan (1970 & 1971) have studied the problems of measuring geographical concept attainment which will determine when a child is ready to begin using maps. Berla' and Nolan (1972) stressed that a child's immediate environment can be used for teaching the concepts of spatial relationships, distance and scale.

Another problem is the lack of information about the parameters determining legibility of tactual symbols. Most of the research effort has been devoted to identifying sets of discriminable symbols in isolation and not in the context of a map. Other areas requiring research are:

(i) Association of meanings with the tactual symbols.
(ii) Stimulus redundancy.
(iii) Information content of symbols.
(iv) Information density.
(v) Physical size of the map.
(vi) Scale - topographical or topological.
(vii) Optimum elevation of symbols.
(viii) Use of reference points and grid systems.
(ix) Use of keys.

Maps can either be made centrally by a professional transcriber, or locally by teachers or sighted volunteers. The advantages of a central facility are that a higher capital expenditure can be justified in order to achieve high quality copies with a relatively low unit cost, and the operator is trained in the translation from a visual map to a meaningful tactual one. At present the majority of maps are made locally by teachers, mobility instructors or sighted volunteers, and financial considerations tend to dominate their choice of production method.

An important, but often neglected, aspect is the drawing of maps by blind people. Variation in the elevation of symbols has been found to be a useful coding dimension but there is still no satisfactory method for blind people to draw multi-height maps and this causes problems in the compatability of symbols produced by different methods.

There have been few systematic studies on the reading and interpretation of tactual maps. A notable exception has been the research by Berla' on tactual scanning strategies but these studies have been confined to pseudomaps.

It is often assumed, probably erroneously, that all potential map users can read braille. Although Gray and Todd (1968) found that 60% of the registered blind population in Britain could not read braille, it is not known how many are able or would wish to use tactual maps.

The area which has suffered the most neglect has been the design of maps for the partially-sighted. Gray and Todd found that 70% of the visually handicapped population had some useful vision. Although visual markings have been printed on tactual maps, little research has been done on the design of maps with both visual and tactual symbols.

Berla' and Nolan (1972) suggested that an ultimate practical goal would be to define those situations and content areas where maps convey either more information than a verbal description or at least convey it more efficiently.

1.1 Design

Tactual maps are composed of three categories of symbols: point symbols to show specific locations or landmarks, line symbols to designate boundaries or lines and areal or texture symbols for areas. The results of experiments on the discriminability of tactual symbols are summarised in Table 1.1.

The four major factors influencing discrimination are:

(i) size

(ii) elevation

(iii) form or configuration

(iv) orientation

(i) Size.

Tactual symbols have to be constructed at a much larger size than visual ones because of the relative inadequacy of touch when compared with vision. The difficulty in trying to define a minimum size is that difference in size may be one of the major factors contributing to legibility among point symbols.

(ii) Elevation.

Variation in height has been used to differentiate between point, areal and line symbols in the context of a map (Wiedel and Groves, 1969) but not within these categories of symbols.

Table 1.1 Results of experiments on the discriminability of tactual symbols.

Author	Material	No. of subjects	Linear: No. of symbols tested.	Linear: No. discriminable	Linear: Length mm	Areal: No. of symbols tested.	Areal: No. discriminable	Areal: Size mm. (square)	Point: No. of symbols tested.	Point: No. discriminable	Point: Max. dimension mm.	Comments
Morris & Nolan (1961)	Virkotype	96				12	5	51				
Culbert & Stellwagen (1963)	Virkotype					40	(11)	50				not full pair-comparison
Morris & Nolan (1963)	plastic	60				7	2	6				
Nolan & Morris (1963)	Virkotype	96	18	3	102				18	1	6.4	
	plastic	96	13	9	102							
	plastic	92				13	7	51				
Schiff (1967)		12				24	4	19				
		12				24	8	25				
	plastic	24							26	17	14.3	upper case letters
Wiedel & Groves (1969)	plastic		17	4		3	1		15	3		method not reported
Nolan & Morris (1971)	plastic	60	13	7	102	11	8	51				
	plastic	58							12	8	5.1	
	plastic	58							12	5	5.1	
	paper	60	21	7	102				19	11	14	

(iii) Form or configuration.

Jansson (1972) found that the following kinds of point symbols are often confused:

(i) Evenly embossed surfaces of different form.

(ii) Closed contours of different form.

(iii) Open contours of different form.

(iv) Combinations of similar units.

(iv) Orientation.

Research by Goodnow (1969) and Pick and Pick (1966) has shown that visually a change in shape is discriminated more easily than a change in orientation, but tactually the reverse is true.

Nolan (1971) studied the relative legibility of raised and incised tactual figures and found that students made 7% more errors and took 38% longer to read the incised figures.

Informal observations, by Wiedel (1965) and others, indicate that many blind students have difficulty in perceiving a tactual version of the visual arrow. Schiff, Kaufer and Mosak (1966) developed a line, saw-tooth in cross-section, which felt smooth in one direction and rough in the other. They compared this symbol with the conventional arrow and found that either symbol was superior in simple diagrams but the special symbol was superior in more complex diagrams. Moreover the special symbol was preferred by the blind subjects in both simple and complex diagrams.

Stimulus redundancy

Schiff and Isikow (1966) varied the degree of redundancy in tactual histograms. They found that the most redundant presentation provided fewest errors when size differences were small. However, when size differences were large, different textures or outlines were effective means of indicating different areas.

Nolan and Morris (1971) made six pseudomaps with two different spacings between symbols and three different heights of embossing. They found that identification of points and lines was best when there was the greatest differentation in symbol height. Identification of points was superior under conditions of maximum symbol seperation.

A considerable amount of research has been done on the use of coding redundancy in a visual presentation. Rappaport (1957) found that adding redundancy degraded identification, but when irrelevancy was added performance improved as a function of the level of redundancy. Landis and Slivka (1972) suggested that a successful measure of the effectiveness of a display should be based on how judiciously an observer can utilize the information presented on a display. Furthermore, it was reasoned that if a change in format really made a difference it should be apparent in the adequacy of the decisions made on the basis of the displayed information.

Tactual scanning

Various studies (Nolan and Morris, 1971; Berla', 1972 & 1973; Berla' and Murr, 1973) found that, in general, subjects used inefficient scanning procedures for locating a symbol on a tactual pseudomap. It was also found that performance could be improved by teaching the subjects to scan the map in a systematic manner.

All these studies used a pseudomap on which the symbols were positioned randomly. In practice a subject will probably have some idea of the structure of the display so that he can add any information into some form of mental image of the map.

Design for the partially-sighted

Nolan (1960) studied the design of pictures for large type textbooks. He compared five different formats:

(i) Simple line drawing.

(ii) Line drawing with areas blacked in for contrast.

(iii) Line drawing with blacked areas and light shading.

(iv) Line drawing with blacked areas and heavy shading.

(v) A photo-offset print.

Using the method of pair-comparison, forty visually handicapped children judged the relative legibility of the five formats. A tracing, consisting of a line drawing with areas blacked in for contrast, was found more legible than the other formats.

Nolan (1961) followed up this work by presenting 106 teachers with illustrations produced by tracing in black and white and by photographing in black and white several pictures originally in colour. Traced pictures were judged preferable for use in large type books by 91% of this group.

Greenberg and Sherman (1970) used 45 partially-sighted subjects to compare the accuracy of discrimination of visual lines on various backgrounds. They found that white symbols on a dark background gave significantly better accuracy in discrimination than black lines on a white background. They also found that thinner lines were discriminable when using white lines on a dark background. They attributed this result to irradiation effects which help to create the illusion that white lines on a dark background appear to be thicker than they actually are.

1.2 Methods of production

The main characteristics of systems for producing multiple copies of tactual maps are summarised in Tables 1.2 and 1.3. The choice of method will depend on the ultimate use of the map and on financial considerations. Traditionally the copies are made on manilla paper but this material imposes physical limitations on the design; there is a limited range of discriminable symbols, relatively low height of embossing and paper is not suitable for

TABLE 1.2 Systems for producing multiple copies.

Method	Base material	Method of duplicating	Quality				Cost of Materials		
			Maximum elevation	No. of different elevations.	Accuracy	Durability	Capital	Master	Copies
Metal foil	Plastic	Vacuum forming	C	C	C	B	B	D	C
String master	Plastic	Vacuum forming	B	B	C	B	B	D	C
Wire master	Plastic	Vacuum forming	B	B	B	B	B	D	C
Solid dot	Paper	Screen printing	D	D	C	D	D	D	D
Sewing machine	Plastic	Vacuum forming	C	C	C	B	B	C	C

A - very high
B - high
C - medium
D - low

TABLE 1.3 Table of the methods of production.

Method	Base material	Method of duplicating	Cost					Quality			
			needs accurate visual master	time to make master	capital cost of equipment	cost of materials for master	cost of materials for copies	maximum elevation	No. of different elevations	accuracy	durability
Embossed zinc plates	paper	press		C	B	C	D	C	D	C	D
Sintered bronze	plastic	vacuum-forming	•	A	B	A	C	B	A	B	B
Metal and epoxy	plastic	vacuum-forming		B	C	C	C	A	A	B	B
Virkotype	paper	deposition	•	C	B	B	C	D	D	C	D
P.V.C. base	P.V.C.	deposition	•	C	B	B	A	C	C	B	B
Photoetching	paper	press	•	C	B	B	C	B	C	A	B
Photolathe	paper	press	•	C	B	C	C	C	D	B	B
Drum embosser	paper		•	C	C	D		C	D	D	C
Relief printer	paper			D	B	D		C	D	D	D
Line embosser	paper			C	A	D		D	D	D	D

A - very high C - medium

B - high D - low

outdoor use. A large number of the systems developed in recent years have employed the vacuum forming of plastic sheets which are more expensive than paper but are more durable and capable of better symbol definition.

It has been found desirable to use more than one height of embossing but many production systems are limited to a single elevation. The optimum elevation of symbols will depend on whether the copies are monolithic, the map is for outdoor use and on the tactile sensitivity of the user. If the production system requires an accurate visual master for each elevation of embossing then the maps can be very expensive when only a few copies are required.

Metal foil

A master for vacuum forming is made by embossing a sheet of aluminium foil. The map has to be drawn in mirror image on the back of the foil which is then placed on a rubber mat and the lines embossed with a spur wheel. Textured areas can be produced by gluing sandpaper to the front surface of the foil.

String master

This method involves building up a master on transparent cellulose. Various thicknesses of string are used for line symbols; sandpapers, linoleum and fabrics are used for textures.

Wire master

This is very similar to the previous method except that solder wire is used in place of string. Solder can be rolled to give solid, dotted or dashed lines with a triangular cross-section. This system is superior to the string method since the solder is easier to manipulate and the lines have sharper crests.

Solid dot

Nippon Lighthouse in Japan have developed a technique for screen printing embossed maps. This system requires no special equipment and can produce multi-coloured maps. The disadvantages include the low elevation of embossing and the poor control over dot profile. Since the visual quality is good but the tactual quality relatively poor, the main application is for people with some useful vision who use both visual and tactual senses to read a map.

Sewing machine

A master for vacuum forming is made by machining a fibrous material with thick thread. Areal and point symbols can be glued to the top surface of the master.

Embossed zinc plates

This system, based on the traditional method for printing braille books, involves embossing a pair of zinc plates on a special machine (Figure 1.1). The

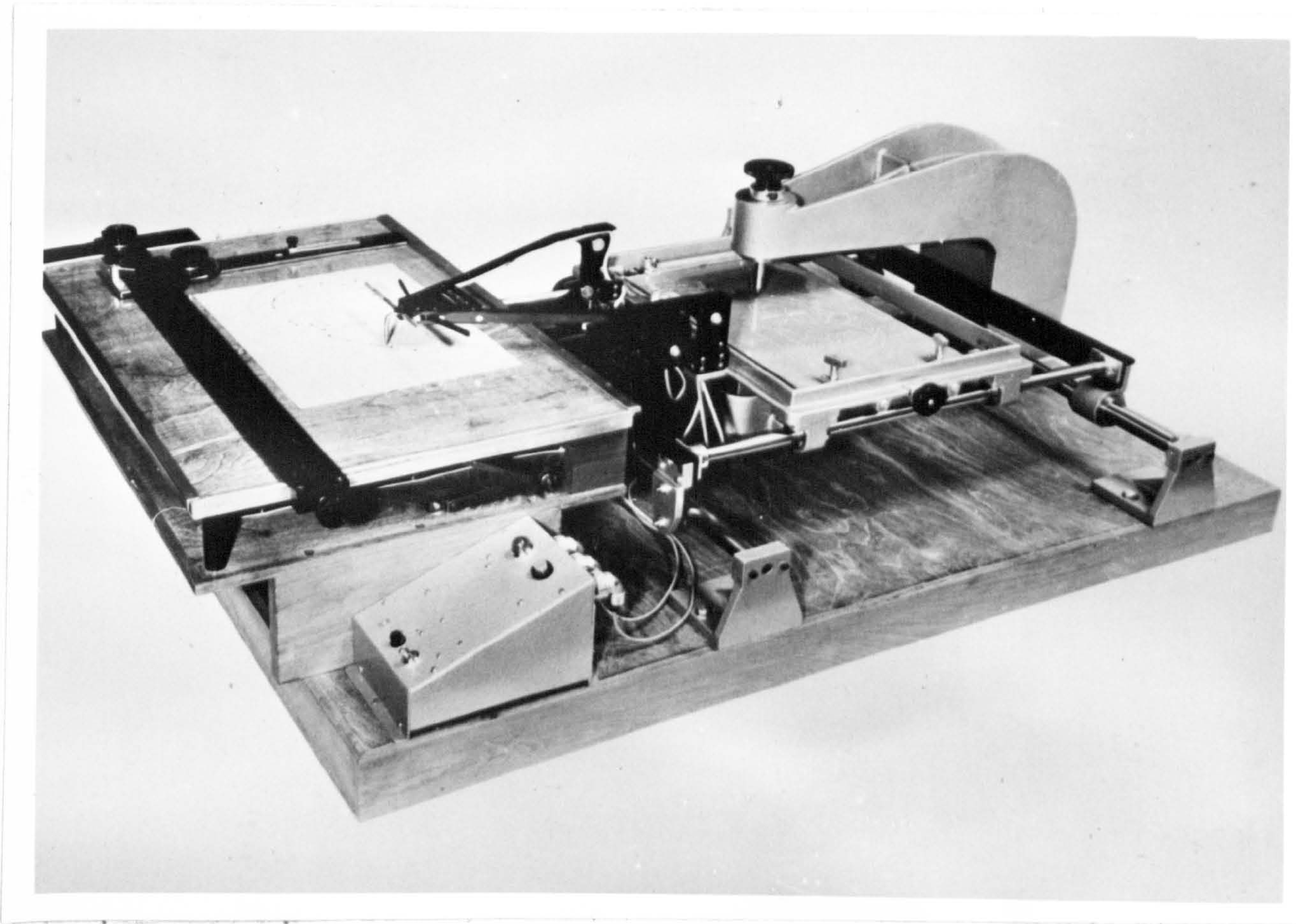


Figure 1.1 Machine for embossing zinc plates
(Courtesy of B.J.Lynes Ltd).

plates are used in a press for making copies in manilla paper. This system is usually limited to producing maps in a punctate form with only one elevation of embossing.

Sintered bronze master

A sheet of sintered bronze is manually engraved to make a female master for the vacuum forming of plastic sheets (Figure 1.2). This system is capable of producing high quality maps but the bronze is very expensive and the engraving can take a few months. In practice the use of a female master gives poor control over the shape of the crest of a line or point symbol, and this affects the discriminability of the symbol.

Metal and epoxy resin master

The male master is made from metal and epoxy resin. Blocks of metal are used for regular shapes and epoxy resin is moulded for the remainder. Since the master is not porous it is necessary to drill air holes in the master before vacuum forming plastic copies. The manufacture of the master is so time consuming that the method is only viable for enthusiastic amateurs.

Virkotype

Wet inkprint is dusted with a fine resinous powder which adheres to the wet ink and appears as a raised plastic symbol when heated. The maximum elevation is

Figure 1.2 The engraving of a sheet of sintered bronze (Courtesy of R.N.I.B.).

relatively low and the system only works reliably under laboratory conditions.

P.V.C. base

The process involves heating resinous powders into a core of about .015 inches (0.38 mm) thickness. During the actual heating process, a master surface mold prepared from a photo-engraved plate applies a raised layer of pigmented vinyl that permanently affixes to the base. The map can be embossed on both sides providing an alternative to overlays (Kidwell and Greer, 1972).

Photoetching

A photographic copy of the map is placed on top of a sheet of photosensitive plastic. This is exposed to ultra-violet light and the master is then chemically etched to the required depth. It is necessary to repeat the whole process for each different elevation on the map. Since both male and female masters can be produced, copies can be made by vacuum forming of plastic sheets or by embossing paper, plastic or metal in a conventional press. This latter facility can be very important when a large number of copies are required.

Photolathe

A lathe is controlled from a photoelectric scanner. The machine developed by Jens Scheel in Germany is limited to a single elevation. Since both male and female masters can be produced, copies can be made of paper in a conventional press.

Drum embosser

In principle this is very similar to the photolathe but the cutting tool is replaced by a solenoid. This system is limited to producing diagrams in a punctate form.

Relief printer

Saab-Scania in Sweden have developed a flat-bed embosser for use in the classroom. The equipment (Figure 1.3) consists of a drawing table and one, or more, reading desks. The reading desk contains a punch for embossing manilla paper. The output is in punctate form with either 3 or 5 dots/cm. The picture can be either enlarged or reduced and the data stored on a conventional stereo tape recorder. Thus diagrams can be stored on the same tape as a 'talking book'.

The system is still in an early stage of development but the potential is enormous if both noise and price can be reduced. It has been suggested that this equipment might be the equivalent in a blind school of the black-board in a sighted school. The capital cost is largo since each pupil would need his own reading desk.

Line embosser

A computer line printer can be modified to produce tactual diagrams by removing the ribbon, increasing the pressure on the hammers and by putting some rubber behind

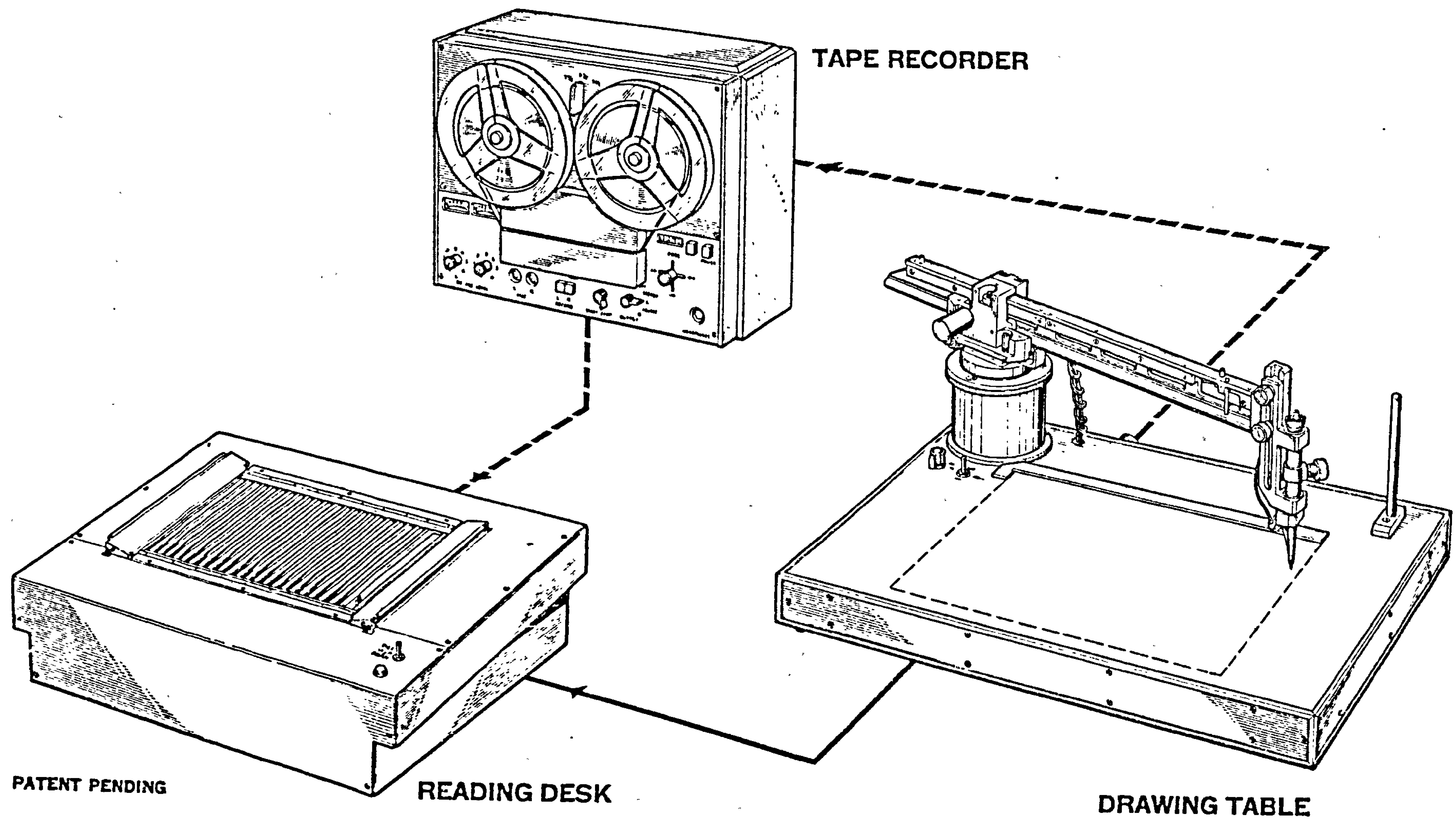


Figure 1.3 Relief printer (Courtesy of Saab Scania)

the paper. Different textures can be produced by using different characters. The physical quality of the output is poor but the significance of the system is that it can be operated by a blind user. Hallenbeck (1969) has written software for the graphical output from computer programs as well as diagrams produced by direct instructions on a teletype.

1.3 Mobility and orientation maps

A mobility map is one which gives sufficient information for independent pedestrian travel by a blind person. An orientation map gives less detailed information about an area.

Leonard and Newman (1970) found that five out of ten subjects could follow, without error, a single route using a spatial-diagrammatic tactual map. No conclusions could be made regarding any superiority of the use of a tactual map against memorizing verbal instructions. In a laboratory study, Maglione (1969) demonstrated that blind and blindfolded sighted subjects could negotiate a maze with significantly fewer errors using verbal instructions and a tactual map than by using verbal instructions alone. Both these studies were done with a uni-directional route although a tactual map can also be used for the return journey.

Leonard (1967) showed that five out of six blind schoolboys were able to make a detour from a specified route and get back on route again using a tactual map. Although Leonard's work included evaluations on subjects' ability to use a tactual map to solve detour problems, it was based mainly on single-route maps. However Leonard (1967) did suggest that "it should not be too difficult to design more complex problems requiring the use of dimensional information; for example, choosing the shorter of two detours".

Bentzen (1971) first demonstrated that a tactual map can "enable independent planning of a variety of routes to a variety of objectives". A novel feature of the map used in this evaluation was the use of overlays to present braille information. The overlay is a seperate sheet which is physically positioned directly over the map. Bentzen's six subjects had no difficulty using the tactual map for route planning, and navigational errors were attributed to poor travel techniques rather than inadequacies in the map. The interaction of travel performance with map reading is an important consideration in devising methods of evaluating the usefulness of tactual maps for travel. Although map reading may be perfect, failure to detect landmarks or estimate distances correctly results in ineffective navigation.

Kidwell and Greer (1972) were interested in non-visual perception of the environment and in particular the type of landmarks that should be represented on a map for the blind. They developed further Bentzen's multiple display and put the braille on the underside of the map. They started by using mirror image braille but found that their subjects preferred ordinary braille. Their map of the M.I.T. campus uses a considerably higher information density than anything previously attempted, but they found that their subjects did not experience any major difficulties with reading the display.

2. Computer-assisted production system

A system was developed to meet the demand for the economic production of high quality embossed maps in small quantities. Due to the complexity of the translation from a visual to a tactual map, computer-aided design techniques were employed for minimising the time taken during the design phase, ease of updating and versatility. The master was engraved on a machine tool controlled from a punched paper tape. An epoxy resin copy of the engraved master was used for vacuum forming plastic copies. Over a hundred masters have now been made by this system.

Since mobility maps are usually required in relatively small numbers, the initial cost of the master copy has to be kept low if the system is to be economically viable. The present methods of reproduction of embossed maps fall into two main categories:

(i) Embossing sheets of paper or plastic in a press with male and female masters.

(ii) Vacuum forming plastic copies.

The first method is relatively inexpensive for producing a large number of copies but the initial cost is high. On the other hand vacuum forming is inexpensive for small runs but the unit cost is high since the plastic sheet is expensive and the process is labour intensive.

For making mobility maps, vacuum forming offers an inexpensive technique for reproducing high quality maps in small quantities. The main problem with this process is the manufacture of a suitable master.

Numerically-controlled machine tools have been used for a number of years for precision machining. The advantages include:

(i) accuracy does not depend on the operator's skill.

(ii) fast turn-round time once the control tape has been prepared.

(iii) the contol tape can be used for making multiple identical copies.

The largest recurrent cost is that of producing the control tape. This can be made using a part-programming language with manual coding of the data. This tends to be time consuming for graphical representations although economically viable for alpha-numerics (Andrew, 1972).

The alternative, to manual coding, is to use computer-aided design techniques for generating the control tape. These techniques have been used for the production of the artwork for multi-layer printed circuit boards and integrated circuit masters. This is very similar to the problem of making embossed maps since both require manipulation of graphical elements during the design phase, and full interpolation in two axes with discrete increments in the third axis.

The design of a tactual mobility map involves:

(i) Specification of the basic geography of the streets or buildings.

(ii) Addition of information of interest to blind users which may include:

- (a) braille annotations.
- (b) adjustment of scale and symbol seperation to improve clarity.

(iii) Design of overlay, underlay and/or grid system.

(iv) Addition of braille or recorded text which may include:

- (a) general description of the map.
- (b) specific information on navigational hazards.
- (c) index of shops or names of streets.
- (d) supplementary information such as bus numbers and routes.

Justification for using computer-aided design

Versatility. The problems of data manipulation are greatly eased when the graphical data is held in digital form on a file. For instance the task of changing the scale of a map is very laborious by any manual method but relatively simple using a digital computer. For research purposes it is often desirable to reproduce the same map a number of times but with one parameter altered each time.

To obtain optimum legibility of symbols it is often necessary to deliberately distort the scale. Sometimes it can also be advantageous to moderately enlarge the area around a complex road junction.

Speed. The time taken to design a tactual map can be significantly reduced because of the ease of manipulating symbols. Also the computer can be used to handle simple tasks such as ensuring that lines are horizontal or vertical.

Update. Since a map can be stored in digital form on tape, it is a simple operation to make a small modification to the map and then produce a new control tape.

Cost reduction. The time taken to design and update a map is greatly reduced and the saving in labour charges outweighs the cost of computing time. With a computer operating in a time-shared mode, the processing time is very small compared with the connection time.

Methods of implementing computer-aided design

The data has to be input to the computer before it can be processed and output to either an on-line or off-line device. The main options in configuration are shown in Figure 2.1.

Input techniques

The input of the data can be a relatively slow process and therefore expensive. If the data for the base map is

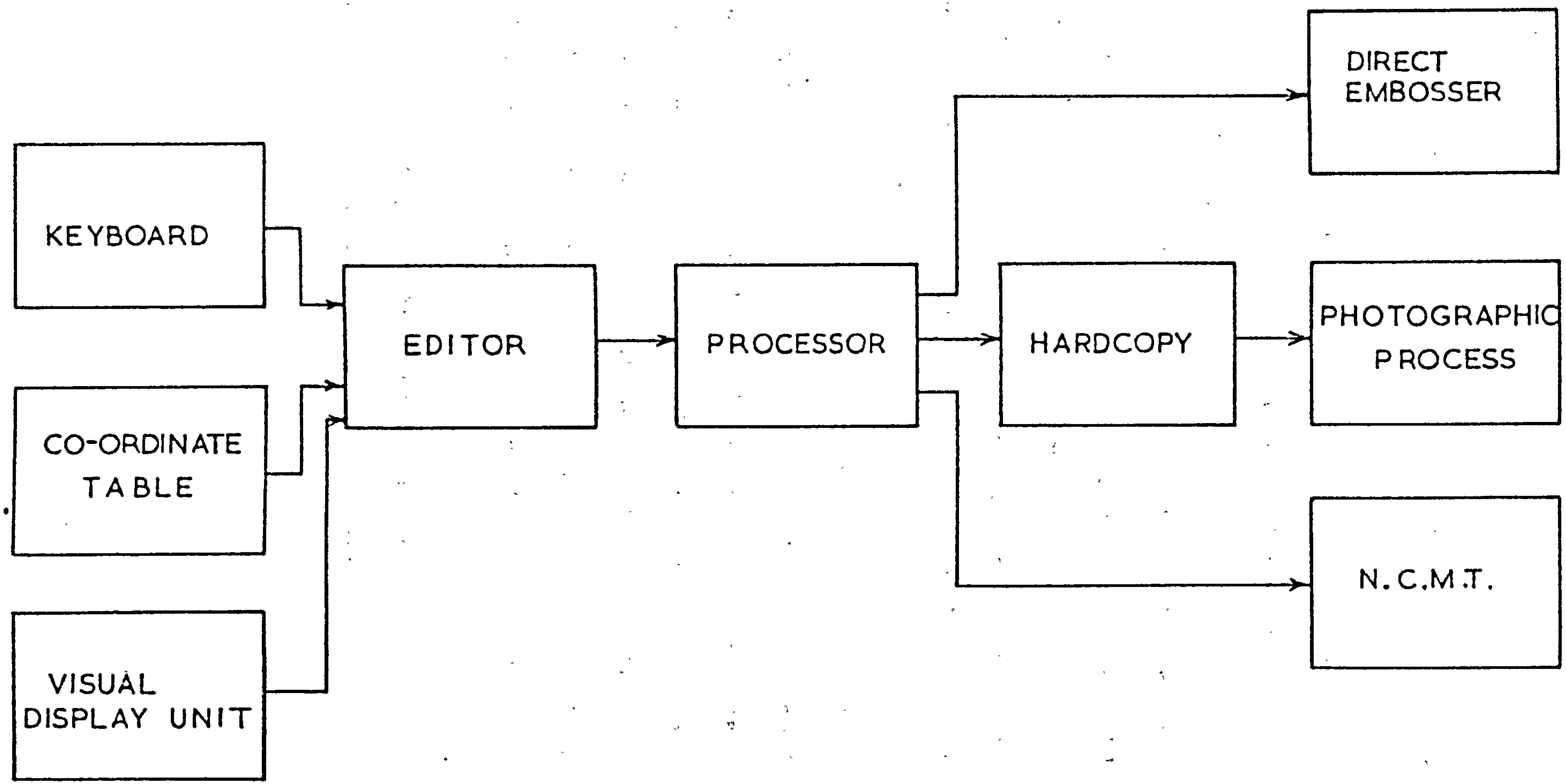


Figure 2.1 COMPUTER-AIDED DESIGN OF TACTUAL MAPS AND DIAGRAMS

already in digital computer-compatable form, the input process can be simplified. Although digital tapes are produced by Ordnance Survey and the Central Intelligence Agency (USA), the cost of deleting superfluous information considerably outweighs the advantages of using this input method.

The alternative techniques for data input are from on-line or off-line keyboards, co-ordinate tables and visual display units. In practice the data will need editing due to operator errors. In a crude system, a visual or tactual hardcopy output could be obtained and the input file then modified.

In order to obtain optimum symbol legibility on a tactual map, a considerable amount of interaction is required between the designer and the data base. Although this may only be simple adjustments such as ensuring adequate symbol seperation, it is essential to try to optimise the man-computer interaction. A disadvantage of using a storage or regenerative interactive display is the lack of direct precision on the screen of the display unit. In this application lack of precision in the x,y co-ordinates is less significant than in the z axis.

Choice of display

A storage tube display has the advantage that it requires no display buffer and no processor time in the quiescent state. The main disadvantage is that the whole display has to be regenerated when a line has to be removed from the display. However this is not a problem with a regenerative display which needs a buffer to continuously refresh the display. The maximum quantity of information that can be displayed on the screen at any one time is determined by the buffer size and the speed of drawing vectors.

The complex translation from a visual map to a meaningful tactual one eliminates the possibility of the process being completely automatic. Usually only a small part of the information on a sighted map is required, or can be accommodated, on the tactual version. The designer also has to decide on the elevations and types of symbols to use for particular features. For instance a compass rose is often replaced by a row of dots across the north edge of the map. A computer could be programmed to ensure that minimum symbol seperation is maintained.

Given adequate store the computer can be programmed to translate text to a good approximation to grade II braille. Due to space considerations, only one or two letters are usually put on a tactual map to represent a street name. In this situation there is little advantage in using grade II instead of grade I braille which is a letter to letter translation of ordinary text.

Often a large print map is required showing the same information as the tactual version. A sighted map can be output on a digital plotter which, preferably, has variable line-width capability.

Output devices

The output from the computer can be to an embosser, digital plotter or numerically-controlled machine tool, all of which can be either on or off-line. The choice of output devices will depend on the type of map and the use for which it is intended.

An embosser can be a modified line printer where the full-stop character embosses ordinary stationary, or a special embosser such as the MIT Braillemboss. These devices are limited to producing single-elevation maps in a punctate form with a fixed matrix of addressable points.

A digital plotter can be used to generate masters for photoetching, photodeposition or photolathe processes such as those developed by Virkotype Corporation, Plastic Lace Inc, Plastron Inc, Dyna-Flex Corporation and Jens Scheel Ltd (see Table 1.3). These systems require precision artwork for each elevation of embossing; the digital computer is idealy suited to this form of data manipulation.

The other alternative is to control a machine tool either from tape or directly from a computer. The data has to be translated by a post-processor but only one tape is needed for a multi-elevation map.

2.1 Input and editing of graphical data

The topographical data can be input to the computer from a co-ordinate table, a visual display unit or a keyboard. The co-ordinate table provides a simple, fast and precise method of input. For this application accuracy is not of prime importance since the data can be edited on the screen of the visual display unit, and the blind user is not taking precise measurements of distance from the tactual map. The main design criteria for developing the co-ordinate table (Figure 2.2) were very low capital expenditure and ease of operation.

The principle of operation is that two wires from the stylus are wrapped round drums on the spindles of two potentiometers. The potentiometers (10 turn and 0.1% linearity) are connected across ±10 volts so that the voltages on the wipers uniquely specify the position of the stylus on the table. The two voltages are read by the analogue interface when an interrupt is triggered by pressing the 'line' button on the co-ordinate table. The system is recalibrated every session by inputting the voltages when the stylus is in the top left hand corner of the table, the top right hand corner and then the origin (see Appendix 5). The axis transformation to give rectangular co-ordinates is shown in Figure 2.3. In use, the operator can input a single node or request the computer to sample the analogue inputs at a predetermined rate for the input of curves.

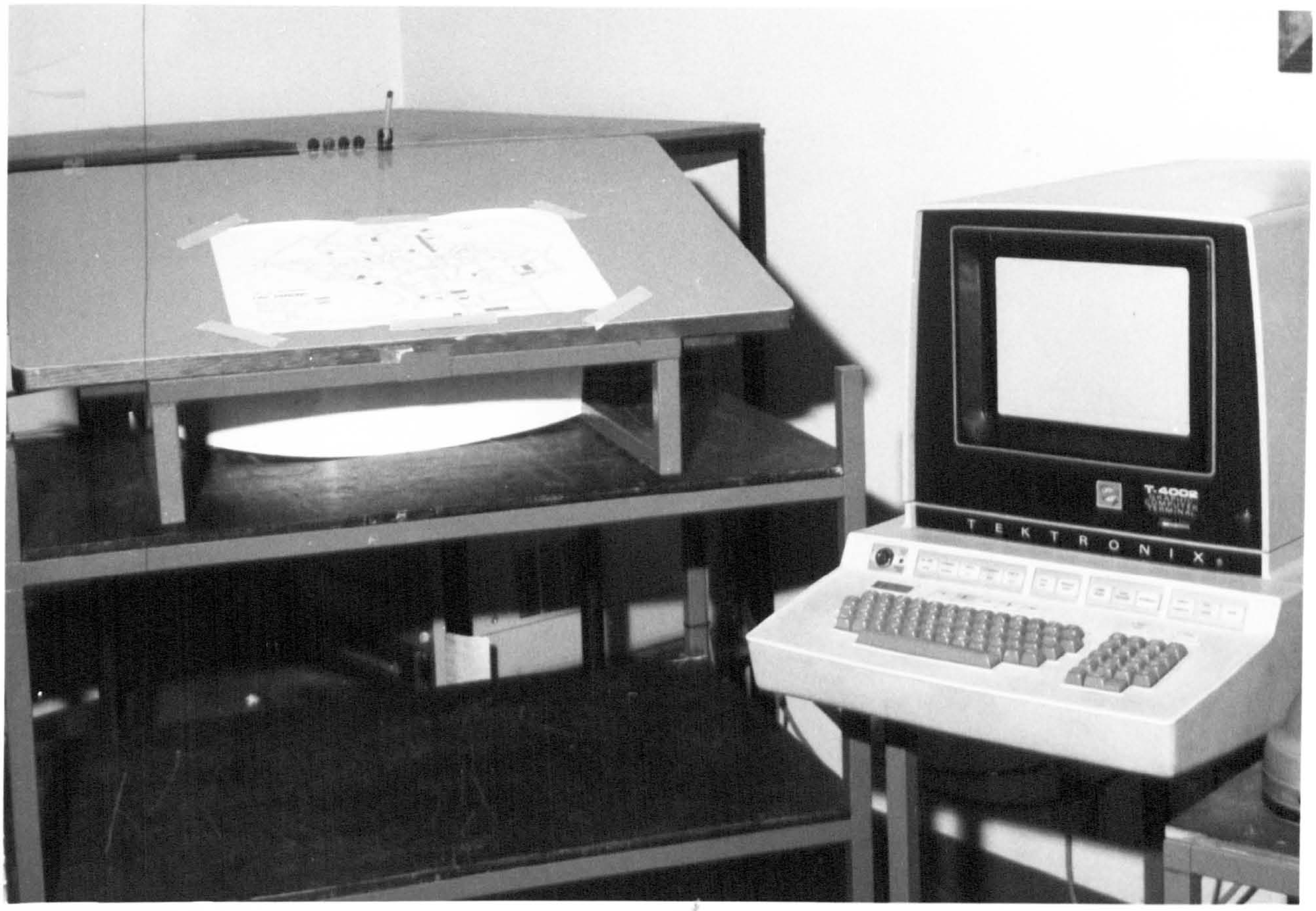
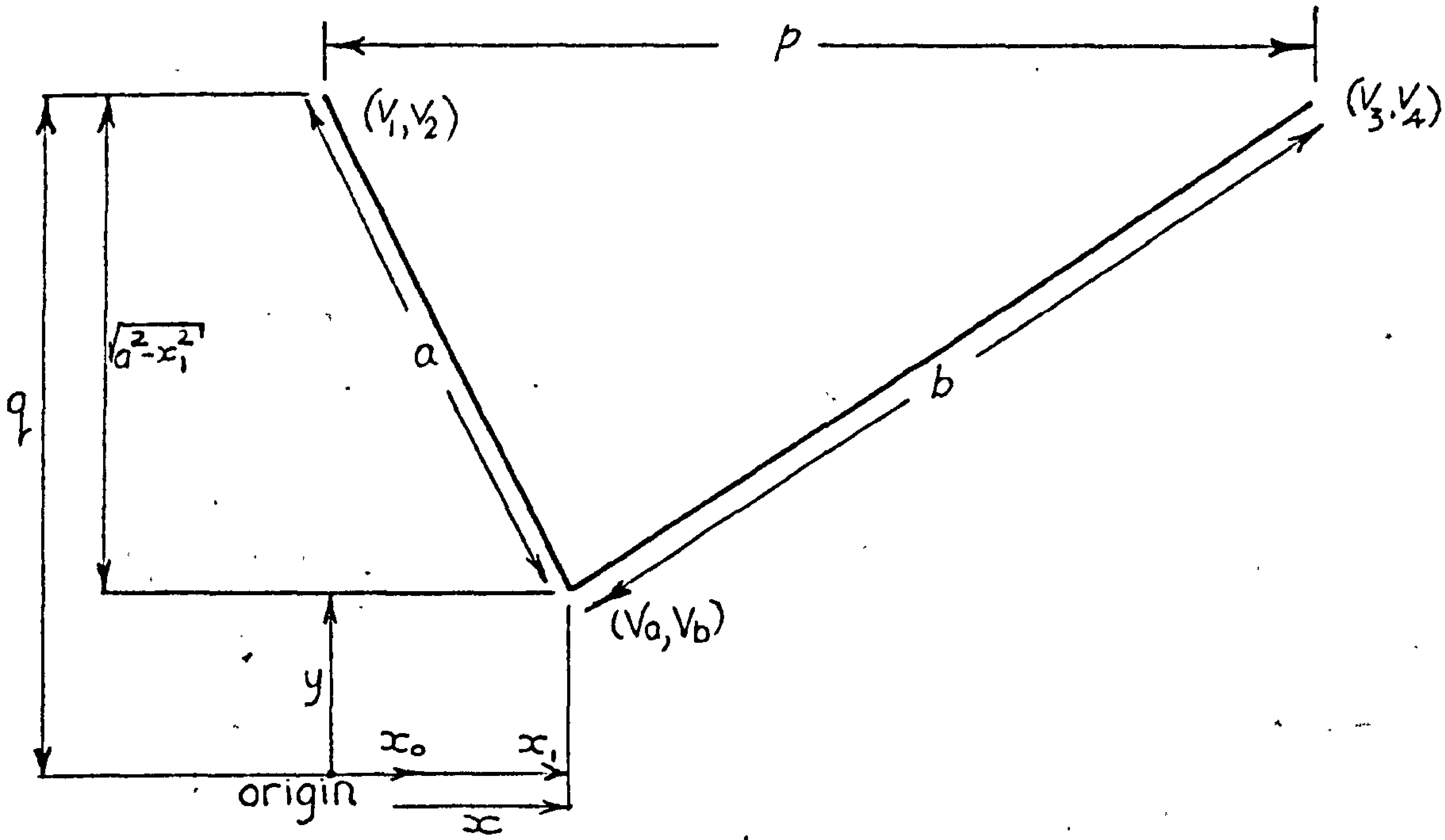


Figure 2.2 Coordinate table and visual display unit.



(v_1, v_2) voltages on wipers of the potentiometers with the stylus in top left hand corner of table

$$a = p * \frac{v_3 - v_1}{v_a - v_1}$$

$$b = p * \frac{v_2 - v_4}{v_b - v_4}$$

$$x = \frac{a^2 + p^2 - b^2}{2p}$$ by trigonometry

$$y = q - \sqrt{a^2 - x_1^2}$$

$$x = x_1 - x_0$$

Figure 2.3 Axis transformation.

The associated computer program permits editing of data on a visual display unit. The program listing, flow charts and operator instruction manual are included in Appendix 5. The operator can communicate with the computer by using the joystick and keyboard (Figure 2.2). The joystick is an analogue device which controls a pair of crosswires on the visual display unit. A storage tube display is used instead of a regenerative display in order to minimise the processor time and core requirements. These factors are significant since the Sigma 5 computer can be operated in a real-time time-shared mode.

Data structure

The display data for a simple map could be held in store but this is not practical for a complex map. The speed of access to a specific item of data will determine the program response time. Therefore the only viable alternative is to store the data on disc. The data structure must be economical on disc space and permit the modification of one node without affecting any other data points.

One data structure which fulfils all these requirements is a table structure with four words per node (four bytes per word). Each node can be described by ICOR, IAB, IX,IY where IX and IY are integer x,y coordinates in units of 0.0005 inches. IAB contains information about the elevation and type of line; for instance IAB = 6512 means line type

12 at an elevation of 65 thou. ICOR is an integer variable which is used for defining macros (groups) of nodes. This facility allows the operator to handle data as either macros or individual lines.

This data structure is limited to specifying dimensions of less than 16.38 inches if the resolution is maintained at 0.0005 inches. The program never holds more than eight words of data in core at any one time.

Facilities

The operator can position the crosswires on the screen using the joystick and the coordinates are transferred to a buffer when a character is input from the keyboard. The character will determine the action taken by the program.

The program is user orientated and the main features are:

(i) Input from a coordinate table, joystick or punched paper tape.

(ii) Insertion and deletion of individual lines or macros.

(iii) Insertion of standard symbols.

(iv) Movement of nodes or macros.

(v) Change of scale.

(vi) Control of elevation and type of line.

(vii) Conversion of text to grade I braille.

(viii) Squaring up of horizontal and vertical lines.

(ix) Paper tape dump of data file.

(x) Output on a digital plotter.

(xi) Output of a control tape for a numerically-controlled machine tool.

2.2 Manufacture of female and male masters

The engraving machine (Figure 2.4) is controlled by a GEC 90/2 computer with the data on punched paper tape. The engraving machine and control program had been developed by J.P.Andrew (1972). The machine tool is controlled in all three axes by stepping motors (0.0005 inch steps) which give precision without complex control systems. The advantage of using a computer-controlled machine tool is that it minimises the amount of data which has to be transferred from the Sigma 5 computer. For instance the data tape just specifies the position of a braille dot but the engraving program causes a small circle to be engraved.

The z axis of the engraving machine is calibrated from a shim resting on the top surface of the material to be engraved. So the depth of engraving is constant only if the thickness of the material does not vary. An alternative method for determining the depth of cut would be to measure the depth relative to the top surface at the current position of the cutter. Unfortunately this is not feasible in this application since the material

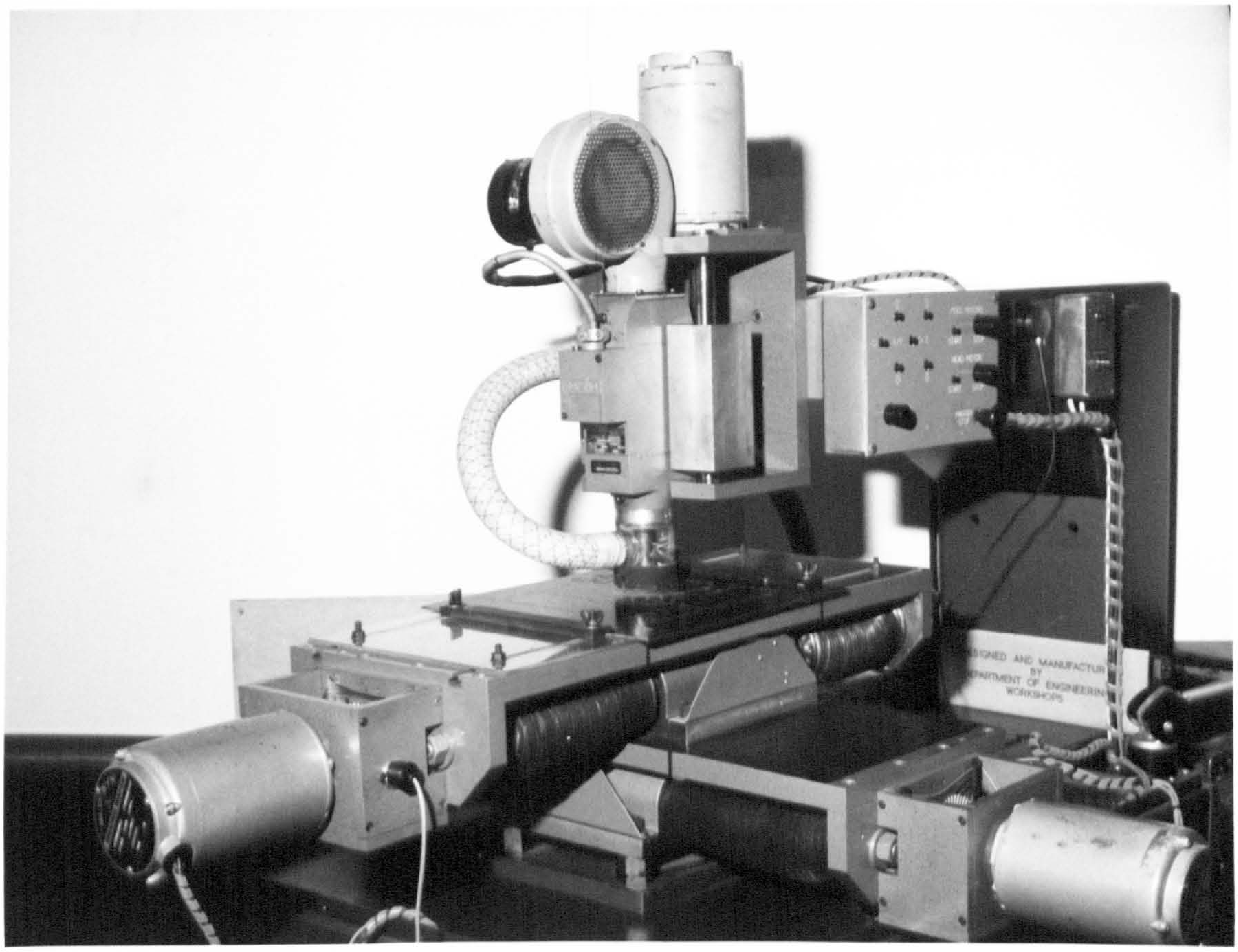


Figure 2.4 The engraving machine.

forms a burr around the edge of the cut.

The map is engraved in mirror-image in 0.093 inch Ketch-brand Tufnol which is a paper and phenolic resin laminated plastic. This material has good machining properties, is available at a constant thickness ($\pm$0.001 inches) and at a reasonable price (£0.29 per lb, £0.19 per sq. ft.). Any gradual variation in thickness will affect the accuracy but not the precision of the elevations on the final copies; for tactual maps precision is more significant than accuracy.

The shape of the cutter on the engraving machine determines the sharpness of the crest of a line and the ability to clear swarf. If the swarf is not cleared then some of it will be compacted into the bottom of the groove. The optimum shape of cutter was found to be that shown in Figure 2.5.

The female Tufnol master is copied in epoxy resin to produce a male master. The epoxy resin found to be best was Hermetite D.B. Toolform for the following reasons:

(i) Detailed reproduction and surface finish.

(ii) Withstood the heat of vacuum forming.

(iii) Neglible shrinkage.

(iv) No deterioration in storage.

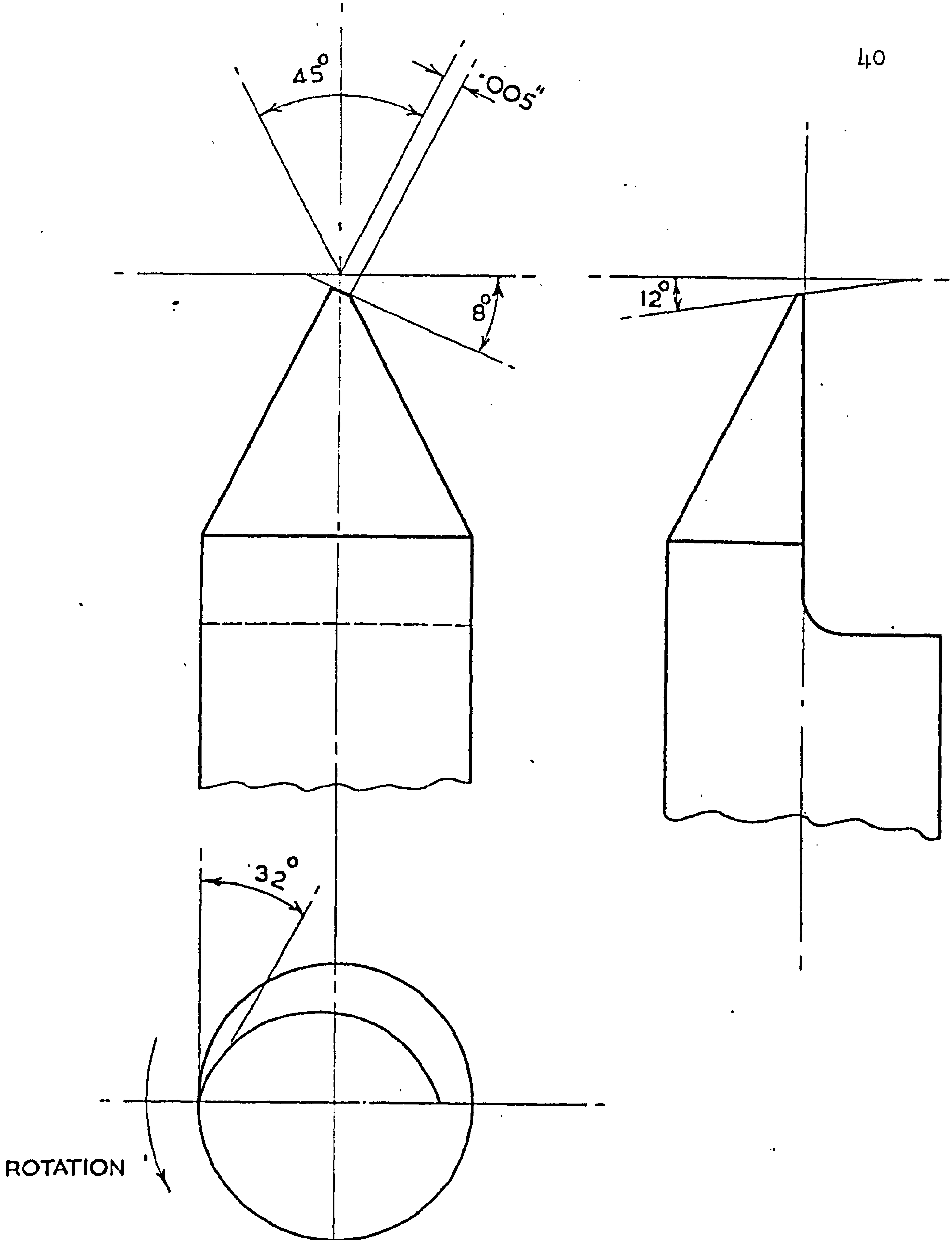
(v) Easy to release from Tufnol.

(vi) Easy to drill vent holes.

(vii) No capital equipment needed.

(viii) Easily available.

(ix) Inexpensive (£0.69 per lb).



Not to scale

Figure 2·5 Engraving cutter

2.3 Vacuum forming

This process involves:

(i) Heating a sheet of thermoplastic.

(ii) Sucking the plastic down to conform to the shape of the mold.

(iii) Cooling the plastic until it regains its original rigidity.

(iv) Removing the plastic sheet from the mold.

The vacuum forming machine, shown in Figure 2.6, is the one in most common use in institutions for the blind, so it was used for this research to ease the problems of compatability. The machine is equipped with a heater which gives a maximum of 2 kW/ft^2 over 11 x 11½ inches, an interval timer and a rotary vacuum pump with no reservoir.

The cycle time of this machine can be improved by spring-loading the clamps and by restricting the frame to 45° movement (see Figure 2.6). The interval timer starts the pump to evacuate the air from under the hot plastic sheet. This arrangement could be improved by using a reservoir tank which is kept permanently evacuated so that the suction required comes from the tank rather than directly from the pump. The material distribution of the plastic would then be improved since a slow draw-down causes excessive thinning at the corners.

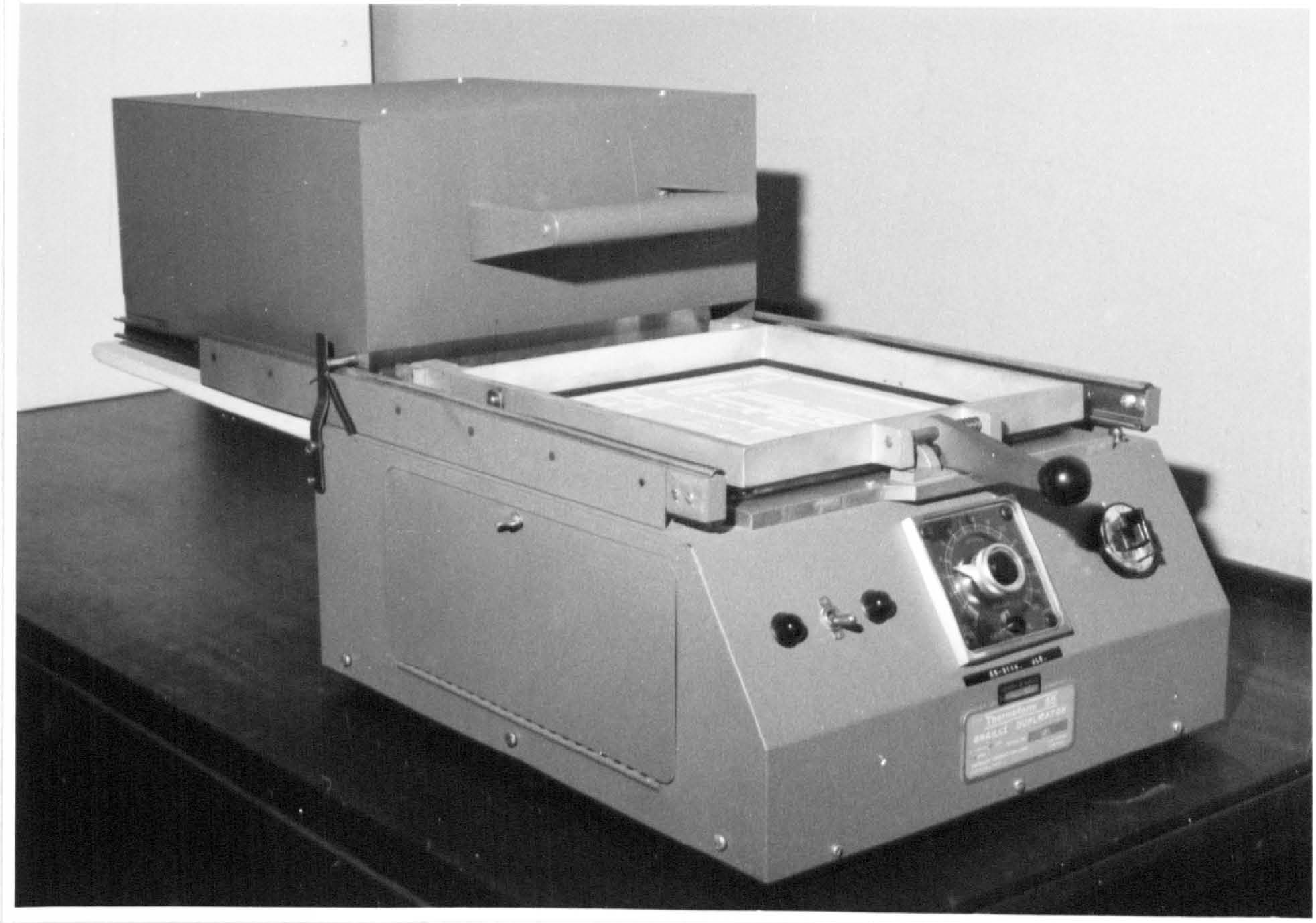


Figure 2.6 The vacuum forming machine.

To obtain the same quality of reproduction across the whole area of forming requires an even temperature distribution since plastic has a low thermal conductivity; for instance polyvinyl chloride has a thermal conductivity of 1.5×10^{-3} W/m °C compared with 2 W/m °C for aluminium. The temperature distribution was measured by using coloured temperature-indicating paint; it was found that after 10 minutes the centre of the working area was at 300 °C but was 230 °C at 1½ inches from the edge and was 155 °C at the edge. The low temperature at the edge is caused by the metal clamping frame which obstructs some of the direct infra-red radiation; this could be improved by using reflectors behind the heating elements. Another method of improving the temperature distribution would be to use a thermally conducting filler, such as aluminium powder, in the epoxy resin master but this would increase the cost of the map.

Both female and male masters can be used but the former will give well defined concave corners but poor reproduction for the convex ones. However the converse is true for a male master and it is the sharpness of the crests which is significant in this application. The quality of reproduction is also dependent on the maximum permissible forming temperature which is higher for an epoxy resin monolithic master than for those using conventional adhesives.

Another important factor is a low temperature gradient through the plastic sheet. Since the plastic is heated from above by the infra-red radiation and by the hot master from below, it is necessary to preheat the master before starting to form copies.

Since epoxy resin is non-porous, vent holes have to be drilled in order to evacuate the air trapped between the plastic and the master. The optimum diameter of these holes will depend on the type of plastic; for instance polyethylene requires smaller holes than polyvinyl chloride. The speed with which the air can be evacuated will affect the quality of forming.

If the same master and vent holes are used for polyethylene as for polyvinyl chloride, there will be small bumps on the back of the polyethylene where it has been sucked into the vent holes. Some blind users have found these bumps useful since they stop the map slipping when it is held against the body.

The plastic sheet should not be removed from the master before it has regained its original rigidity. This process can be accelerated using forced air cooling on the top surface of the plastic sheet.

Choice of plastic

The degree of softening produced by heating the thermoplastic must be uniform and sufficient for it to be adequately formed by a pressure of 14 lb/in^2, and the surface must not be decomposed by infra-red radiation.

Other factors which need to be taken into account include:

(i) Cost.

The cost of plastic sheet is dependent on the quantity bought. Manufacturers of thermoplastics normally process relatively large batches so, although plastic sheet can be produced with specific characteristics, it is only economically viable for the small consumer to buy a plastic which is part of a manufacturer's standard range.

(ii) Reproduction of detail.

The accuracy of reproduction is dependent on the thickness of the plastic sheet and the degree of thinning during the forming process. Although thinning tends to give sharper corners, it can produce high stress levels which lead to failure of the plastic during use.

(iii) Surface texture.

Many users find that a non-absorbent smooth surface is uncomfortable to read but this problem can be alleviated by using a calendered plastic. However the vacuum forming process tends to lessen the effect of calendering particularily when high temperatures are used. Calendering can improve the forming properties of a plastic since it increases the air gap between the plastic and the master.

(iv) Speed of forming.

The vacuum forming process is time consuming so a reduction in the heating and cooling times of a plastic will significantly affect the cost of making copies.

(v) Flexibility.

If a map is to be bound in a book it is usually desirable to use a rigid plastic. Overlays are sometimes made from thin plastic sheet so that the map can be felt through the overlay. Maps are made from flexible polyethylene when they have to be kept in a pocket or handbag.

(vi) Durability.

Some plastics are unsuitable for outdoor use since they become brittle and crack in cold weather. Also the softening temperature of the plastic should be well above those encountered during normal use.

(vii) Internal stresses.

If stresses are introduced in the plastic during manufacture they can cause creasing when the plastic is being formed. This is particularily noticeable in Brailon but it varies from batch to batch.

(viii) Printing.

It is often desirable to include visual markings for the partially-sighted and sighted (see section 2.4), but some plastics do not readily accept printing ink. With a transparent plastic the visual markings can be put on the underside of the map.

Seven plastics were tested for user acceptability and the main characteristics are summarised in Table 3.3.

2.4 Visual markings

It is often desirable to include visual markings on a tactual map for the partially-sighted and the sighted. The amount of useful vision among the partially-sighted can vary considerably so that it is difficult to specify optimum line widths and character sizes. For economic reasons it is usual to restrict the markings to a single high-contrast colour such as black on a white background.

Any technique for adding visual markings, as part of the production system described earlier, must be economic for small quantities. This effectively eliminates conventional offset printing which is only viable for quantities of over a thousand. Ogrosky (1973) tried using mimeography with some success but the contrast was inferior to that produced by offset printing. The markings can be added by hand with paint or a suitable spirit-based felt pen but this is both time consuming and produces results of variable quality.

Generation of the artwork

Program CADEMD (see Appendix 5) can output a full-scale visual map on a digital drum plotter which is fitted with a ballpoint pen. A black line (1.2 mm width) could be produced by replacing the ballpoint with a Staedtler pen but this would require some modification to the plotter. This output could be used as a large-print map or as the artwork for a photographic process for including visual markings on the tactual map. An alternative method for producing the artwork would be to cut a stencil; the engraving machine could be modified to do 'cut-n-strip'.

Transparent maps

Transparent plastics have the advantage that visual markings can be put on the underside of the map after vacuum forming. This avoids any problems of alignment and means that the markings will not deteriorate by the abrasion of the user's fingers.

One method tried was to roll ink across the back of the polyethylene sheet so that the embossed lines are left clear (see Figure 2.7). This has the advantage that it results in light coloured lines on a black background as recommended by Greenberg (1968).

Another possible method would be to fill the back of the embossed lines with black ink which gives black lines on a light background. One problem with this approach is finding an ink of the correct viscosity which will adhere to polyethylene.

Both these systems, which are labour intensive and give variable quality of markings, are unsuitable for research applications. However they could be useful to the amateur map-maker since there is no capital expenditure.

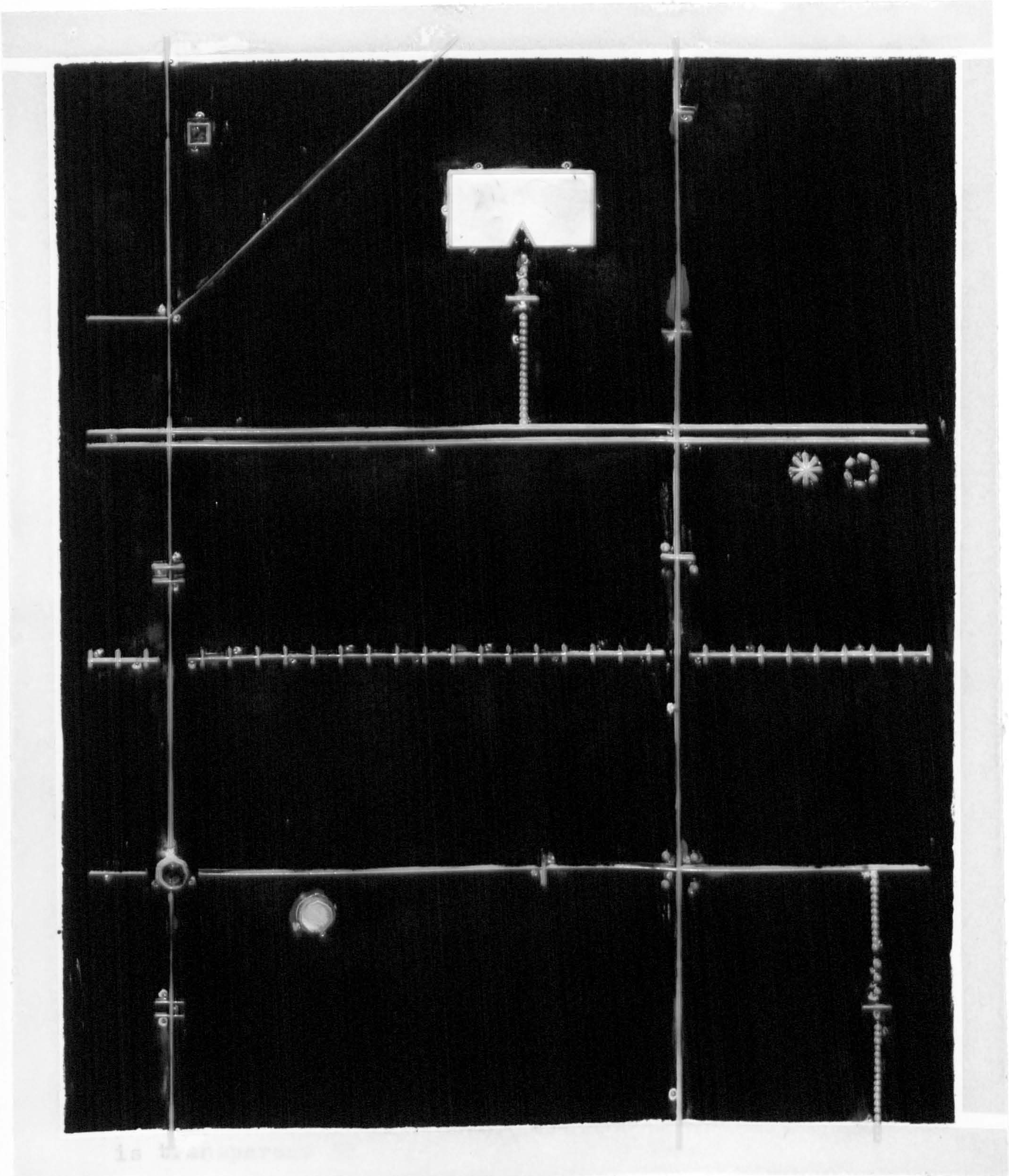


Figure 2.7 Polyethylene map with ink rolled on the back.

The other methods which were examined involved adding the markings to the plastic before vacuum forming. Care has to be taken to ensure registration of the visual and tactual symbols. The ink also has to be able to withstand the temperatures involved in vacuum forming.

Photocopying

One method to avoid the markings being rubbed off is to fuse the visual image into the top surface of the plastic. This involves very precise temperature control so that the top surface melts without melting the whole sheet; this proved beyond the capability of a standard photocopier for the thermoplastics in Table 3.3. Another drawback is that there is no copier in a major manufacturer's standard range which will accept sheets eleven inches wide.

If these problems could be overcome photocopying could offer a fast and inexpensive method for including visual markings.

Screen printing

The basic process involves:

(i) A digital plot is produced on a material which is transparent to ultra-violet radiation.

(ii) A photo-resist emulsion is applied to a screen.

(iii) The screen is exposed to the ultra-violet light through the contact print.

(iv) The screen is then washed in water.

(v) The screen is dried and then exposed to more ultra-violet radiation to set the emulsion.

(vi) The thermoplastic sheets are screen printed with a suitable ink.

This process takes about a man-hour to produce the screen and print ten copies. Screen printing has a decreasing unit cost so it is the most economical system, of those currently available, for producing a hundred copies.

If a negative is made from the digital plot by photographic techniques, then polyethylene can be printed on the reverse side and the designer has full control of line widths and can add inkprint annotations. Since polyethylene is transparent there are few problems of alignment when vacuum forming.

These investigations have not provided a satisfactory solution for making ten copies although the digital plotter seems to provide a fast economic method for obtaining the artwork.

2.5 Manual production system

There is a limited requirement for a simple manual system for the production of high quality tactual maps without high capital expenditure. A manual version was developed of the output system described in section 2.2. This system involves:

(i) The manual engraving of a sheet of Tufnol.

(ii) A male copy is produced in epoxy resin.

(iii) Plastic copies are reproduced on a vacuum forming machine.

The manual engraver (Figure 2.8) consists of a free-moving horizontal table with a cutter which can move vertically. The cutter, driven by a single-phase 6000 rpm motor, can be moved vertically by a foot pedal and the depth of cut can be preset by an eccentric cam. The stylus, which is used to follow the lines on the visual map, is directly connected to the table but a stencil is used to help the operator obtain smooth lines and precise symbols. Braille has to be coded manually although the stencil provides for precise positioning of the dots; the Perspex stencil was made using program CADEMD and the numerically-controlled engraving machine.

The system has the following advantages:

(i) Low capital and material costs.

(ii) Requires little space and can be housed on a large table.

(iii) Can produce maps with various elevations of embossing.

(iv) Braille, with various cell sizes, can be included at any angle to the horizontal.

(v) Any number of symbols with various elevations and in any orientation can be produced.

(vi) Smooth curves can be drawn.

The major disadvantages are:

(i) There is no interactive design capability so the system lacks the versatility of the computer-aided design system.

(ii) It is labour intensive.

(iii) There is no facility for changing the scale although a pantograph could be connected between the stylus and the table.

(iv) The quality deteriorates rapidly for elevations over 1 mm since the control forces required become relatively large. An example is shown in Figure 2.9 of a map with the maximum symbol elevation.

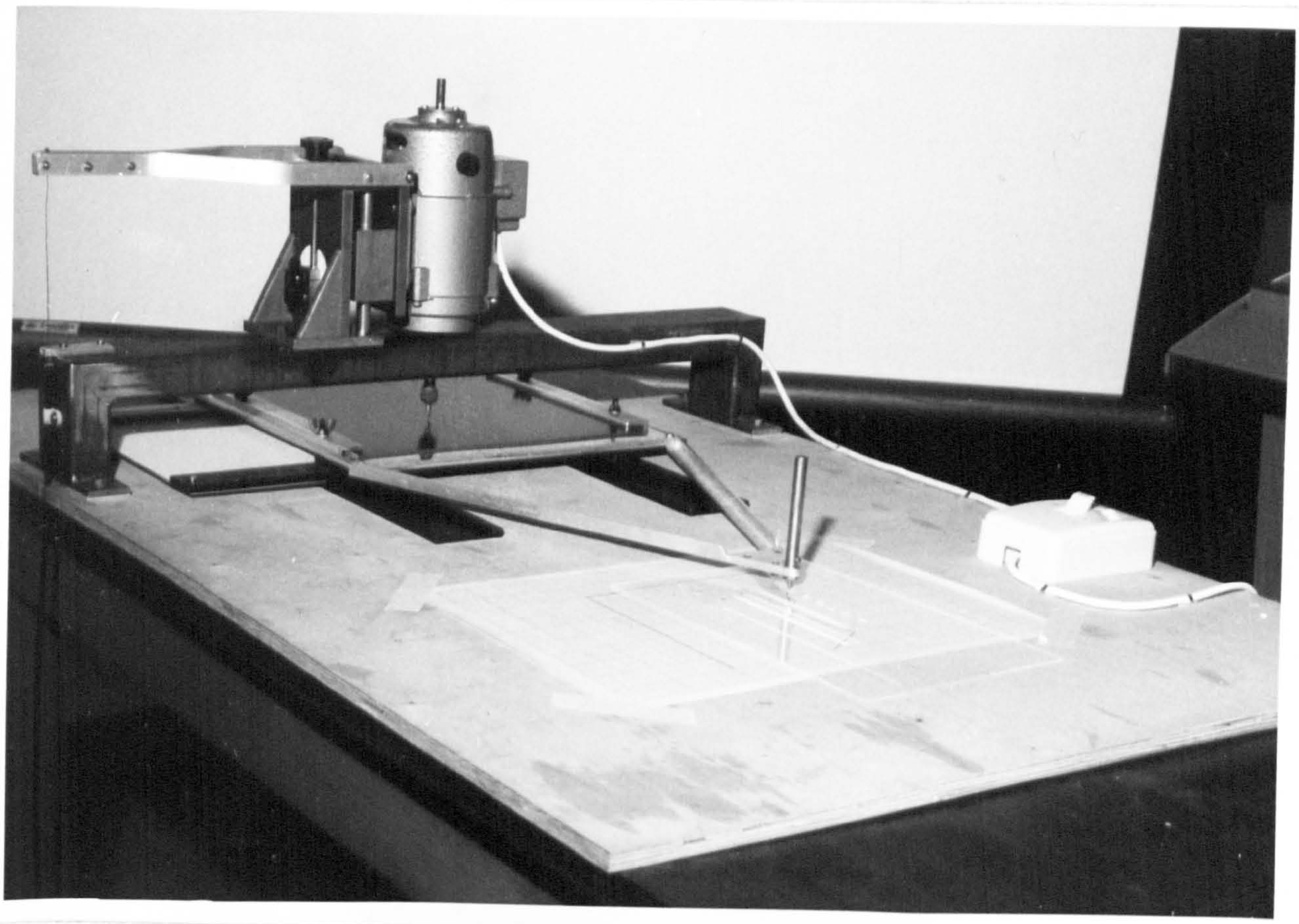


Figure 2.8 The manual engraver.

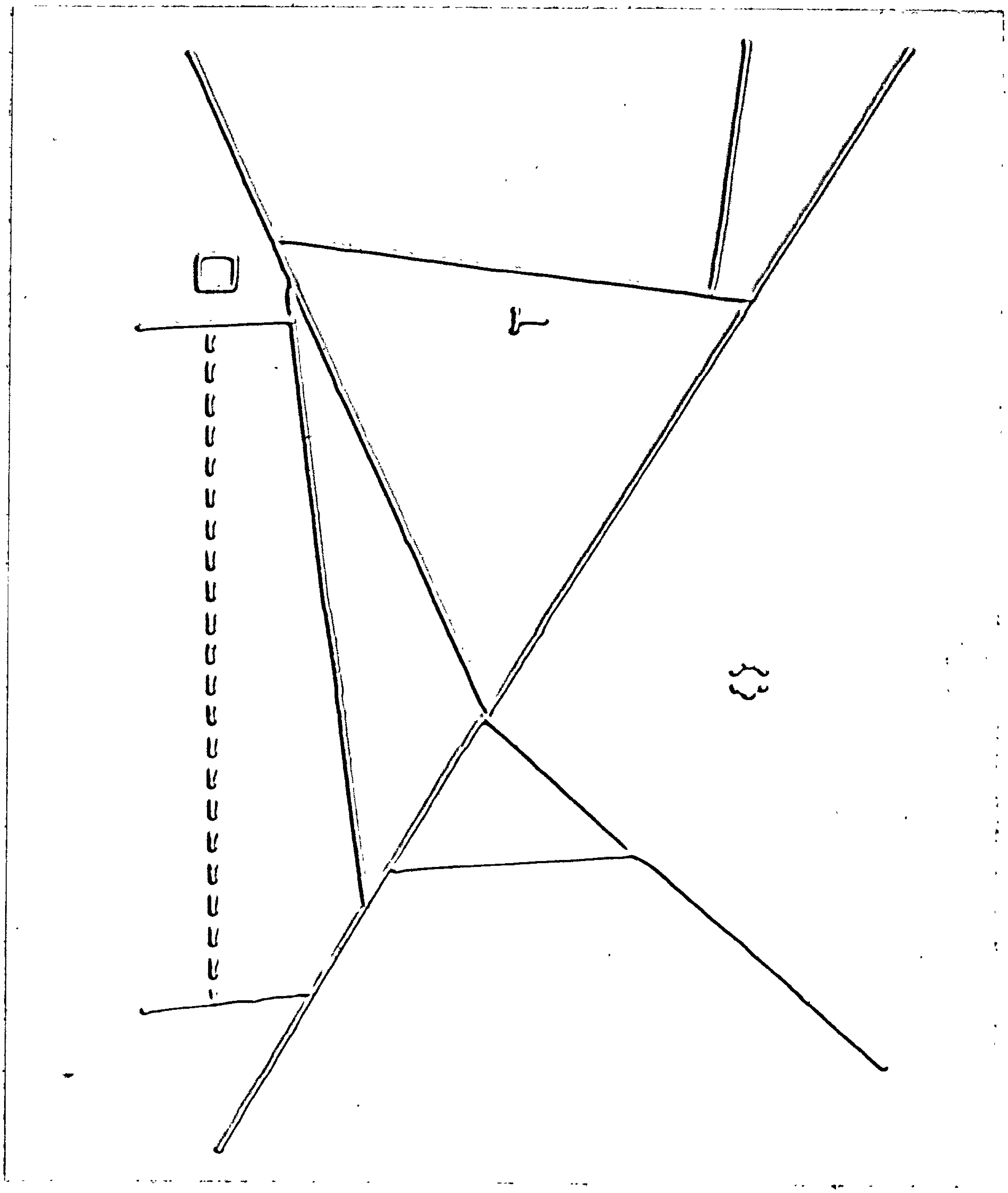


Figure 2.9 Example of a map produced by the manual engraving system.

2.6 Conclusions

The computer-assisted production system has proved a useful tool for research and it seems to offer an economic method for the routine production of mobility and orientation maps. The main advantages of this system are quality, versatility and speed although the latter could be improved by including a commercial digitizer and a regenerative interactive display.

When the Sigma 5 computer is enlarged to enable three jobs to be time-shared, it will be economically viable to connect the engraving machine direct to the Sigma 5 with the data stored on magnetic tape instead of punched paper tape. If the engraving machine is not being used to capacity, it will be feasable to produce textures made up of a large number of elements.

If the necessary finance were available the system could be modified to produce larger size maps. It would be essential to replace the vacuum forming machine so that some of the disadvantages of the present machine could be overcome.

No entirely satisfactory method has yet been found for including visual markings on a tactual map although the digital plotter output seems to offer an economic and fast method for obtaining the artwork.

The production of braille text is at present done manually with copies vacuum formed in thin plastic sheet. This process could be speeded up by using an on-line braille embosser with a computer program to translate text to a good approximation to grade II braille.

A number of the maps made by this production system were supplied to local blind people for informal evaluation. Copies of these maps are included in Appendix 7; they are of four basic types:

(i) Talisman Square, Kenilworth. This is a reference map of a small shopping precinct. The map is intended for use at home, and gives the names of shops as well as the main product sold by each shop.

(ii) Rootes Hall, University of Warwick. This map covers a single floor of an inside of a building. The flexible map is usually kept in a pocket at the back of the book, but it is bound in this appendix to avoid it being lost.

(iii) Coventry. This map covers three routes with double-line representation of roads. This map is intended for users with little previous experience with tactual maps.

(iv) Leamington Spa. This town orientation and reference map includes a grid system and braille on the map. The index gives the grid references for each street as well as the name abbreviation which appears on the map.

No formal evaluation of these maps has been possible due to the lack of facilities needed for such experiments. However all these maps have been used by blind people, most of whom have had little previous experience with tactual maps.

3 Design of mobility and orientation maps.

An embossed map consists of areal, line and point symbols which are used to denote features and landmarks. A raised area can be used as a symbol, but for moderate elevations only the edges are discriminable.

Two experiments (see Appendices 6.2 and 6.3) were undertaken to identify sets of discriminable symbols. Five out of eight areal symbols were found discriminable by the criteria suggested by Nolan and Morris (1971). These symbols were tested at a size of 50 mm square which is much larger than symbols usually found on tactual maps. Areal symbols at a smaller size require a greater density of stimuli; with the computer-assisted production system this can be achieved at the expense of increasing the engraving time, or by adding areal symbols to the top surface of the epoxy resin master (see example in Appendix 7.3).

In the second part of the first experiment it was found that ten out of seventeen line symbols met the criteria for discriminability. Of these ten symbols, seven occupy relatively little space so appear practical for use on a tactual map. In practice symbol size usually has to be small so that the individual elements making up the symbol have to be small; for instance the minimum discriminable length of a dotted line will depend on the distance between the dots.

The second experiment studied the discriminability of point symbols for a large number of blind subjects who were grouped as schoolboys, schoolgirls, adult braille readers and adults who do not read braille. For the schoolchildren, thirteen point symbols (5 mm maximum dimension) met the criteria suggested by Nolan and Morris (1971). This is a considerable improvement over previous experiments and was probably due to the relatively high average intelligence of the schoolchildren (mean IQ = 120.5), and the good physical definition of the symbols.

In comparison to the schoolchildren, the adult braille readers made twice as many errors per person, but their mean age was 44.6 years. Most experiments on the design of tactual maps are conducted with schoolchildren, but these figures indicate that such experiments might tend to give over optimistic results for the likely potential map user population. From the results of this experiment it seems probable that only a small proportion of the adults who do not read braille could use anything but the simplest tactual map.

These experiments only studied the discriminability of symbols in isolation as discrete stimuli and not in the context of a map where a meaning has to be associated with a symbol. So the next experiment studied the retention of meanings associated with fourteen tactual symbols and the ability of the blind schoolchildren to locate these symbols on a map (see Appendix 6.4). The results emphasised the importance of symbols which have informational properties, for example the multi-height symbol for steps. This is a class of symbol which has tended to be neglected due to the limitations of some of the production systems in current use.

This experiment also showed that inefficient techniques were used by the majority of subjects for scanning the map. This problem could be overcome with training although the blind users would probably learn more efficient scanning techniques if they had more experience with tactual maps.

Since there was no significant difference in performance of the group which used a key and the one which relied on memory alone, it is probably advantageous to put the key on a seperate page when the maps are in book form since the key cannot then be confused with the map itself; this design has been used in the tactual maps in Appendix 7.

In general, design parameters need to be studied in the context of a realistic tactual map with a representative sample of the potential user population. The extent of this population is at present unknown which is, in part, due to the scarcity of tactual maps.

The experiments on discriminability form a good basis for the extension of the range of symbols and, in particular, for the identification of the parameters which determine legibility of multi-height symbols. However the results of such experiments will be dependent on the production system and on whether the copies are monolithic.

The production of embossed maps with visual markings was mentioned in section 2.4. However it is necessary to identify the section of the visually handicapped population who can benefit from such maps as compared to just a tactual or large-print map. One problem, in designing an experiment for this purpose, is to create satisfactory measures for the amount of useful vision for each subject; a Snellen rating would not be adequate for this application.

3.1 Comparison of the acceptability of four parameters.

This experiment was a pilot study on the acceptability of four parameters which are under the control of the map designer:

(i) Double and single line representation of roads.

(ii) Choice of plastic.

(iii) Symbol elevation.

(iv) Methods for marking road names.

A series of maps were made of the same area of Leamington Spa with one parameter varied each time. The maps were made at a scale of 1:3500; one of the maps is shown in Appendix 7.4. Fifteen blind adults were used as subjects (7 male, 8 female; mean age = 40.1 years, SD = 14.2 years). All the subjects could read grade II braille.

The maps were made with solid line symbols for roads although Wiedel and Groves (1969) found that tracking was easier for broken or dotted lines. Their findings were based on the use of a production system which gave relatively poor symbol definition so that a solid line could not easily be distinguished from the background. The other symbols used on the maps in this experiment are shown in the key in Appendix 7.4.

Double and single representation of roads

Two parallel lines have usually been used to represent a road since this format was considered easier to conceptualise. Moreover if a large scale is employed, the shape of the pavements at road junctions can be shown on the map; this information can be useful to a blind pedestrian. However single line representation has the advantage that it takes up less space on the map. There has been no published work on the comparison of these two forms of representation.

Two maps were produced in Brailon (0.2 mm) with solid lines at 0.9 mm elevation and without any point symbols. These maps only varied in that one used double line representation for roads (0.4 mm between lines) and the other single line.

Subjects were instructed:

"Here is a tactual map with two parallel/one single line representing the roads. Examine this map systematically either in rows or columns, working from the centre outwards or from the edge inwards.

Now find the map pin in the bottom right hand corner of the map. Now the pin in the top left hand corner of the map. Please trace the route, without going an unnecessarily long way round, from the bottom pin to the top pin via the pin in the centre of the map and being careful to stay on the road."

The order of presentation was determined randomly and the second map was rotated by 180°. Subjects were scored for time and distance; the results are shown in Table 3.1. The subjects were then asked "Which map represents a road best?" and "Which map is easier to read?"; the answers are shown in Table 3.2.

Table 3.1 Mean scores for tracing a route on a map with double and single line representation (N=15).

Representation	Time (seconds)		Mean distance. inches
	mean	S.D.	
Double	29.9	16.4	13.1
Single	22.4	13.7	13.2

Table 3.2 Answers to questions on double and single line representation of roads (N=15).

Question	Double	Single	Neither
Which map represents a road best?	11	2	2
Which map is easier to read?	5	7	3

Choice of plastic

The technical factors which affect the choice of plastic for copies of the map were discussed in section 2.3.

The subjects were given two minutes to study the same map reproduced on seven different types of plastic. They were then asked to score each plastic on a 1 to 5 scale on three criteria:

(i) Texture (1-unpleasant texture, 5-pleasant texture).

(ii) Outdoor use (1-bad for outdoor use, 5-good for outdoor use).

(iii) Symbol definition (1-bad symbol definition, 5-good symbol definition).

The results are shown in Table 3.3.

Table 3.3. Mean scores (1 to 5 scale) for acceptability of various plastics (N=15)

Tradename	Technical description	Usual colour	Thickness mm	Cost pence m^{-2}	Speed of vacuum forming	Texture	Outdoor use	Symbol definition
Bextrene	high impact toughened polystyrene	white	.25	13.2	fast	3.5	3.2	4.1
Brailon	calendered semi-rigid polyvinyl chloride	cream	.1	15.2	fast	3.0	2.7	4.0
Brailon	calendered semi-rigid polyvinyl chloride	cream	.2	41.5	slow	4.0	3.8	4.1
Cobex	calendered rigid polyvinyl chloride	white	.25	17.6	fast	4.0	3.4	4.4
Flovic	polyvinyl chloride co-polymer foil	white	.1	7.6	fast	2.5	3.1	3.7
Flovic	polyvinyl chloride co-polymer foil	white	.25	30.2	average	3.6	3.0	4.5
Polythene	high density polyethylene	trans-parent	.25	26.9	slow	2.1	4.2	3.9

Symbol elevation

Wiedel and Groves (1969) suggested that the height of lines should be "at least twice as high as that of braille dot to be employed". If a symbol is too low it will not be discriminable and if too high will tend to mask adjacent symbols. No research has been reported on the optimum symbol elevation.

The optimum elevation will depend on:

(i) Information density.

(ii) Symbol size.

(iii) Production system - monolithic copies, material for copies and symbol definition.

(iv) Whether the map is to be used outside in cold weather.

(v) User acceptability.

The subjects were given one minute to examine the same map reproduced in Brailon (0.2 mm) with five different elevations of symbols. They were then asked to score each map on a 1 to 5 scale on three criteria:

(i) Comfort (1-uncomfortable, 5-comfortable).

(ii) Distinctness (1-indistinct, 5-distinct).

(iii) Ease of scanning (1-difficult to scan the map in a systematic manner, 5-easy to scan the map in a systematic manner).

The results are shown in Table 3.4 and Figure 3.1.

Table 3.4. Mean scores (1 to 5 scale) for the acceptability of various symbol elevations (N=15)

Line elevation, mm		Point elevation, mm		Comfort	Distinctness	Ease of scanning
mean	SD	mean	SD			
0.40	.01	0.66	.02	3.4	2.8	3.5
0.63	.03	1.00	.02	4.0	4.1	3.9
0.85	.05	1.24	.03	4.1	4.5	4.1
0.98	.04	1.57	.02	4.0	4.7	4.1
1.19	.02	1.94	.02	3.5	5.0	4.1

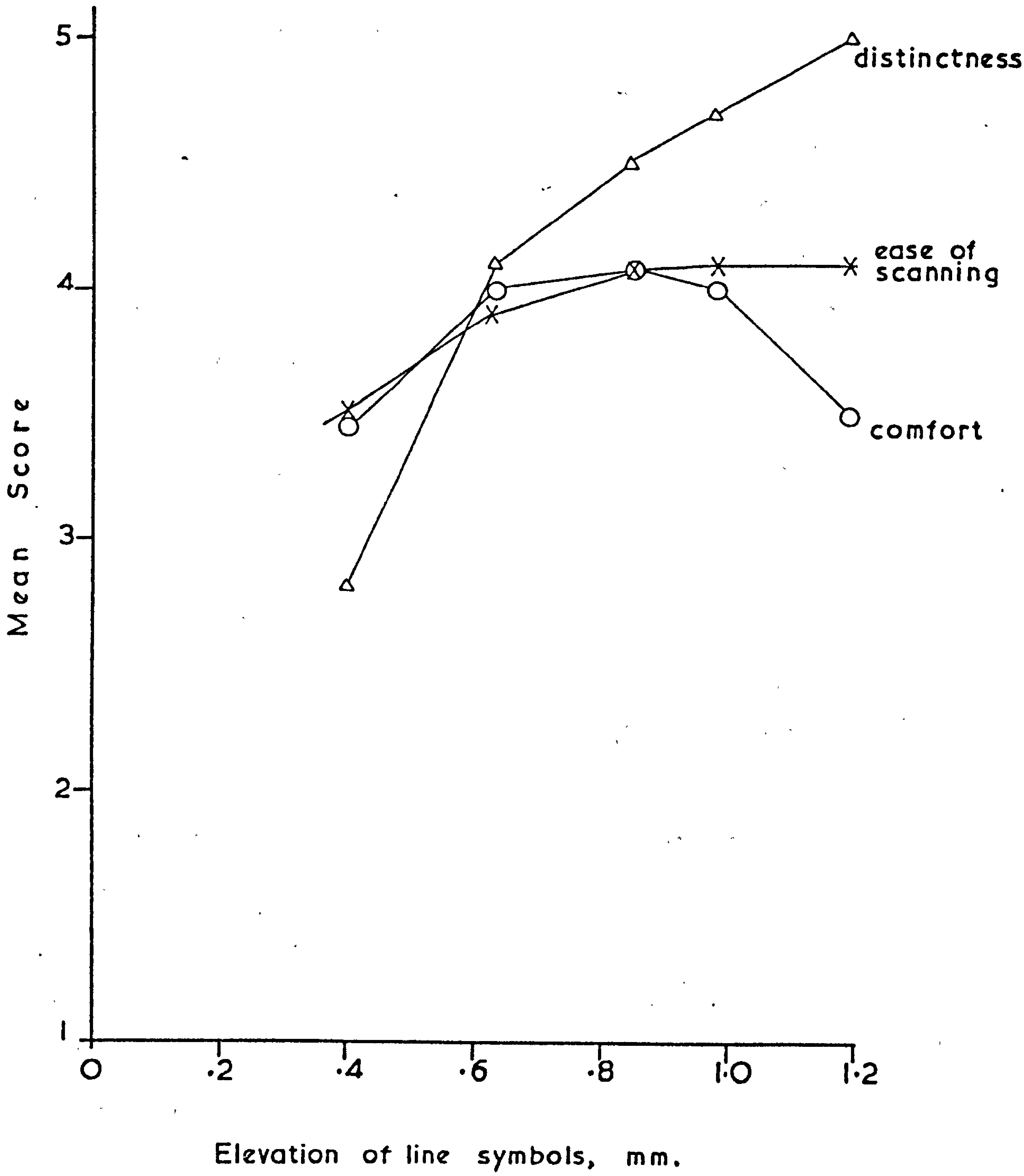


Figure 3.1. Graph of mean scores (1 to 5 scale) for the acceptability of various symbol elevations (N=15).

Methods for marking road names

There is often insufficient space on a map for braille annotations so the text is put on a seperate sheet as an overlay or an underlay. Bentzen (1971) was the first to use a tactual overlay which is a seperate sheet positioned directly over the map; the user has to read the overlay with one hand and the map with the other. Kidwell and Greer (1972) developed the underlay which is similar to the overlay but is positioned under the map with the embossing downwards. This system has the advantage that the map and underlay can be glued together to form a single sheet.

The aim of this experiment was to compare the use of an overlay, and underlay and braille on the map. The map was made up in book form with an index of street names, key, grid and map (see Appendix 7.4).

The grid has letters horizontally and numbers vertically. The index is of the form:

AL   Arlington Avenue (T8,T14)

where AL is the abbreviation on the overlay, underlay or on the map itself, and (T8,T14) are the grid references for the two ends of the road.

The subjects were randomly allocated to one of three groups - overlay, underlay or braille on the map. Use of the index, key and grid was explained to the subjects who were then asked to do fourteen tasks (Figure 3.2). There was a time limit of two minutes for subjects to complete

Figure 3.2 The fourteen tasks for comparing the methods for marking road names.

1. What feature is at Q13?
2. What feature is at M4?
3. Please find the road at M12.
4. What two letters represent the name of this road?
5. What is the full name of this road?
6. What are the two letters for the road at U3?
7. What is the full name of this road?
8. What are the two letters for the road at Q7?
9. What is the full name of this road?
10. What is the grid reference for Morton Street?
11. Can you please find Morton Street on the map.
12. Can you please find Arlington Avenue on the map.
13. Can you please find the toilet on the map.
14. What is the name of the nearest road to the toilet?

each task. Scores for errors and response times were recorded; a summary of the results is shown in Table 3.5.

Discussion

The subjects were not required to use the information for navigational purposes but, in practice, maps are often used for learning the basic topography of an area. A limitation of this type of experiment is the subjects' lack of experience with tactual maps; when asked about the extent of their previous map experience one answered 'a good deal', eight answered 'some' and six 'very little or none'.

In the first part of the experiment, the tracking times for single line roads were significantly less than for double line roads (Spearman's Rho = 0.68, t for significance = 3.24 which is significant for $p<.01$). Single line maps are cheaper to make and use less coding space; for instance it would not have been possible to include the braille abbreviations on the double line map due to lack of space. However the double line is useful when teaching blind children because there are fewer conceptual problems.

When a map is to be used outside, and so has to be kept in a pocket or handbag, polyethylene seems to be the best material for vacuum formed copies. From the results in Table 3.3, Cobex appears to be a satisfactory material for when the map is to be bound in a book, particularily since it is much cheaper than 0.2mm Brailon.

Table 3.5. Mean errors and times for the tasks specified in Figure 3.2 (N=5 for each group).

Question	Overlay		Underlay		Braille on the map	
	% error	time, sec	% error	time, secs	% error	time, secs
1	0	36.8	0	28.6	40	76.0
2	0	37.8	20	20.4	40	68.0
3	0	26.6	0	16.8	20	44.2
4	0	19.4	0	14.8	0	8.8
5	0	25.6	0	16.8	0	25.6
6	60	48.6	20	34.8	40	71.8
7	0	14.0	0	13.6	20	25.6
8	20	43.8	40	30.2	20	58.8
9	0	18.8	0	12.0	20	34.4
10	0	23.0	0	35.4	40	67.0
11	0	52.0	0	40.2	40	90.6
12	20	82.4	20	70.8	80	103.6
13	0	26.4	0	25.4	60	66.2
14	20	62.2	20	42.4	40	61.8
Mean	8.6	37.0	8.6	28.7	32.9	57.3
Mean on q. 1,2,3,5,7, 9,10 (A)	0	26.1	2.9	20.5	25.7	48.7
Mean on q. 4,6,8,11, 12,13,14 (B)	17.1	47.8	14.3	36.9	40.0	65.9
Ratio A/B	0	.55	.20	.56	.64	.74

This experiment did not test the materials over a long time interval or over a large temperature range; some plastics become brittle under these conditions.

The elevation of a symbol will govern the minimum spacing between symbols such that both are still discriminable. The answers concerning symbol elevation might have been different if the map had had a higher information density. However the optimum line symbol elevation for comfort is about 0.85 mm (see Figure 3.1).

There were too few subjects to obtain any significant results for the comparison of methods for marking road names. The design of the experiment was such that half the questions were not dependent on the system employed (question numbers 1,2,3,5,7,9,10). Question 13 was system dependent since braille on the map increases the number of symbols and so makes it harder to locate a specific point symbol, although the symbol was at a much greater elevation than the braille.

For this group of adults (age range 21-66 years) the mean response time for these questions was significantly correlated with age (Spearman's Rho = 0.76, t for significance = 4.22 which is significant for $p<.001$). This means that it may be necessary to design a simpler reference system for the older blind.

4 Conclusions

To permit a scientific evaluation of various design parameters requires a flexible facility for the production of precise tactual maps. This has been provided by using computer-aided design to reduce the operator's time and a numerically-controlled machine tool to give the required precision on the final master.

This research facility could form the basis for a production unit to meet some of the demand for tactual maps and diagrams. Compared with methods for producing maps of similar quality this system has the advantages of versatility, speed, ability to update and low running costs. The speed and quality could be improved by incorporating the modifications suggested in section 2.6.

The four psychophysical experiments, which studied various aspects of map design, helped identify some of the significant factors which determine legibility of tactual graphical representations. In particular, these experiments have helped in choosing symbols which are suitable for use on a tactual map.

Future research on individual design parameters should be done in the context of realistic tactual maps. Experiments on this subject have been hampered by the lack of map experience of the potential user population. The extent of this population can only be estimated when more maps are made available.

A number of maps have been made and distributed to local blind people. This has provided useful feedback and the most important finding from these informal evaluations was the lack of problems encountered by most of the users.

BIBLIOGRAPHY

1 AMOR D. COLOURED MAPS FOR THE LOW VISION BLIND. MOBILITY MAP CONF, NOTTINGHAM, ENGLAND, SEPT 1972.

2 ANDREW J.P. THE STEPPING MOTOR AS A MACHINE-TOOL ACTUATOR. ELECTRONICS & POWER, VOL 18, FEB 1972, PP 62-63.

3 ANGWIN J.B.P. MAPS FOR MOBILITY. PARTS I & II. THE NEW BEACON, MAY 1968, PP 115-119; JUNE 1968, PP 143-145.

4 ARAMPATTA D. ILLUSTRATIONS IN SOCIAL STUDIES TEXTBOOKS AS THEY AFFECT THE VISUALLY HANDICAPPED. SPECIALIST IN EDUCATION THESIS, GEORGE PEABODY COLLEGE FOR TEACHERS, 1970.

5 ARMSTRONG J.D. (ED) PROCEEDINGS OF CONFERENCE ON MOBILITY MAPS, SEPT 1972. SOUTHERN REGIONAL ASSOCIATION FOR THE BLIND/ UNIVERSITY OF NOTTINGHAM, TO BE PUBLISHED.

6 ARMSTRONG J.D. (ED) THE DESIGN AND PRODUCTION OF MAPS FOR THE VISUALLY HANDICAPPED. MOBILITY MONOGRAPH NO. 1, UNIVERSITY OF NOTTINGHAM, 1973.

7 AUSTIN T.R. & SLEIGHT R.B. ACCURACY OF TACTUAL DISCRIMINATION OF LETTERS, NUMERALS AND GEOMETRIC FORMS. J. EXPTL. PSYCHOL., VOL 43, 1952, PP 239-247.

8 AUSTIN T.R. & SLEIGHT R.B. FACTORS RELATED TO SPEED AND ACCURACY OF TACTUAL DISCRIMINATION. J. EXPTL. PSYCHOL., VOL 44, 1952, PP 283-287.

9 BAILEY J.L. MEANINGFUL MAPS FOR THE BLIND AND SEEING. NEW OUTLOOK, VOL 50, NO. 3, MARCH 1956, PP 77-83.

10 BARR R.L. EMBOSSING ARABIC LETTERS AND NUMBERS ON NEW RAISED-LINE POLYETHYLENE PAPER: AN AID FOR THE BLIND. SCIENCE, VOL 169, 1970, PP 94-95.

11 BARTLEY S.H. THE PERCEPTION OF SIZE OR DISTANCE BASED ON TACTILE OR KINESTHETIC DATA. J. OF PSYCHOLOGY, VOL 36, 1953, PP 401-408.

12 BARTLEY S.H., CLIFFORD L.T. & CALVIN A.D. EFFECT OF VISUAL IMAGERY ON TACTUAL AND KINESTHETIC SPACE PERCEPTION. PERCEPT. & MOTOR SKILLS, VOL 5, 1955, PP 177-184.

13 BAUER H.J. DISCRIMINATION OF TACTUAL STIMULI. J. EXPTL. PSYCH., VOL 44, NO. 6, DEC 1952.

14 BEATON T. TACTILE MAP MAKING FOR THE BLIND. LANTERN LIGHT, VOL 5, NO 1, JUNE 1971, PP 5-6.

15 BENTZEN B.L. AN ORIENTATION AND TRAVEL MAP FOR THE VISUALLY HANDICAPPED: HAND PRODUCTION, TESTING, AND COMMERCIAL REPRODUCTION. MASTER'S THESIS, BOSTON COLLEGE, 1971.

16 BENTZEN B.L. & JAMES G.A. SURVEY ON MOBILITY MAPS FOR THE BLIND. PROC. OF MOBILITY MAP CONFERENCE, NOTTINGHAM, ENGLAND, SEPT 1972.

17 BENTZEN B.L. PRODUCTION AND TESTING OF AN ORIENTATION AND TRAVEL MAP FOR VISUALLY HANDICAPPED PERSONS. NEW OUTLOOK, VOL 66, NO. 8, OCT 1972, PP 249-255.

18 BERLA' E.P. BIBLIOGRAPHY ON TACTUAL PERCEPTION. UNPUBLISHED, AMERICAN PRINTING HOUSE FOR THE BLIND, MARCH 1971.

19 BERLA' E.P. TACTUAL ORIENTATION PERFORMANCE OF BLIND CHILDREN IN DIFFERENT GRADE LEVELS. AMERICAN PRINTING HOUSE FOR THE BLIND, 1972.

20 BERLA' E.P. & NOLAN C.Y. TACTUAL MAPS: A PROBLEM ANALYSIS. ICEBY,MADRID,1972

21 BERLA' E.P. BEHAVIORAL STRATEGIES AND PROBLEMS IN SCANNING AND INTERPRETING TACTUAL DISPLAYS. NEW OUTLOOK, VOL 66, NO. 8, OCT 1972, PP 277-286.

22 BERLA' E.P. EFFECTS OF PHYSICAL SIZE AND COMPLEXITY ON TACTUAL DISCRIMINATION PERFORMANCE OF PRIMARY AGE BLIND CHILDREN. EXCEPTIONAL CHILDREN, VOL 38, OCT 1972, PP 120-124.

23 BERLA' E.P. STRATEGIES IN SCANNING A TACTUAL PSEUDOMAP. EDUCATION OF THE VISUALLY HANDICAPPED, VOL 5, NO. 1, MARCH 1973, PP 8-19.

24 BERLA' E.P. & MURR M.J. SEARCHING TACTUAL SPACE. AMERICAN PRINTING HOUSE FOR THE BLIND, 1973.

25 BEST A.B. MAKING MAPS FOR THE BLIND. PERKINS SCHOOL FOR THE BLIND, MASS., APRIL 1969.

26 BLAKE M. GEOGRAPHY AND THE BLIND: A MODERN APPROACH. NEW BEACON, APRIL 1944.

27 BLASCH B.B., WELSH R.L. & DAVIDSON T. AUDITORY MAPS: AN ORIENTATION AID FOR VISUALLY HANDICAPPED PERSONS. NEW OUTLOOK, VOL 67, NO. 4, APRIL 1973, PP 145-158.

28 BLISS J.C. & CRANE D.H. TACTILE PERCEPTION. RESEARCH BULLETIN, VOL 19, JUNE 1969, P 205.

29 BLISS J.C. A PROVISIONAL BIBLIOGRAPHY ON TACTILE DISPLAYS. IEEE TRANS MMS-11 NO. 1, MARCH 1970.

30 BLUST V. VALUE OF MAPS OR MODELS IN MOBILITY TRAINING. UNPUBLISHED REPORT, AMERICAN PRINTING HOUSE FOR THE BLIND, 1967.

31 BORING E.G. SENSATION AND PERCEPTION IN THE HISTORY OF EXPERIMENTAL PSYCHOLOGY. NEW YORK: APPLETON-CENTRY-CROFTS, 1942.

32 BOTTRILL J.H. LOCOMOTOR LEARNING BY THE BLIND AND SIGHTED. PERCEPTUAL & MOTOR SKILLS, VOL 26, FEB-JUNE 1968, PP 282.

33 BROWN M.S. & STRATTON B.M. THE SPATIAL THRESHOLD OF TOUCH IN BLIND AND SEEING CHILDREN. J. OF EXPTL. PSYCHOLOGY, VOL 8, 1925, P 442.

34 CALVIN J.S. & CLARK J. INFLUENCE OF TYPE CHARACTERISTICS ON BRAILLE READING. UNPUBLISHED MANUSCRIPT, AMERICAN PRINTING HOUSE FOR THE BLIND, 1958.

35 CARMON A. STIMULUS CONTRAST IN TACTILE RESOLUTION. PERCEPTION PSYCHOPHYS., VOL 3, NO 4(A), 1968, PP 241-245.

36 CARP F.M. RECOGNITION OF TACTUAL FORMS BY SIGHTED AND BLIND SUBJECTS. AMER. J. PSYCHOL., VOL 76, 1963, PP 488-491.

37 CHANG C. & JOHNSON D.E. TACTUAL MAPS WITH INTERCHANGEABLE PARTS. NEW OUTLOOK FOR THE BLIND, VOL 62, NO 4, APRIL 1968, PP 122-124.

38 CLARE, SISTER GEOGRAPHY IN THE SECONDARY MODERN SCHOOL FOR THE BLIND. TEACHER OF THE BLIND, VOL 47, APRIL 1959, PP 70-72.

39 CRATTY B.J. MOVEMENT AND SPATIAL AWARENESS IN BLIND CHILDREN AND YOUTH. CHARLES C. THOMAS, 1971.

40 CRAVEN R.W. THE USE OF ALUMINIUM SHEETS IN PRODUCING TACTUAL MAPS FOR BLIND PERSONS. NEW OUTLOOK, NOV 1972, PP 323-330.

41 CRITCHLEY M. TACTILE THOUGHT: WITH SPECIAL REFERENCE TO THE BLIND. RESUME OF PRESIDENT'S ADDRESS, PROCEEDINGS OF THE ROYAL SOCIETY OF MEDECINE, VOL 45, LONDON, 1953, P 281.

42 CULBERT S.S. & STELLWAGEN W.T. TACTUAL DISCRIMINATION OF TEXTURES. PERCEPTUAL & MOTOR SKILLS, VOL 16, NO. 2, APRIL 1963, PP 545-552.

43 CURTIS C.K. TEACHING GEOGRAPHY TO BLIND STUDENTS: A PLEA FOR INVESTIGATION. NEW OUTLOOK, VOL 65, NO. 6, JUNE 1971, PP 187-189 & P 194.

44 CURTIS J.F. & WINER D.M. A COMPARISON OF THE EFFICACY OF TWO METHODS OF MOBILITY TRAINING FOR THE BLIND, USING BLINDFOLDED SIGHTED SUBJECTS. RESEARCH BULLETIN, NO. 22, DEC 1970, PP 119-129.

45 CUTSWORTH T.D. AN ANALYSIS OF THE RELATIONSHIP BETWEEN TACTUAL AND VISUAL PERCEPTION. PSYCHOLOGICAL MONOGRAPHS, VOL 44, NO. 1, 1933.

46 DAVEY B.L. A SURVEY OF HISTORY, PHILOSOPHY, AND RESEARCH IN ORIENTATION AND MOBILITY. UNPUBLISHED, NORFOLK: OLD DOMINION UNIVERSITY, 1968, 83 PP.

47 DAY G.F. SIMPLIFIED EMBOSSED ELECTRICAL CIRCUIT DIAGRAMS. UNPUBLISHED, NOV 1970.

48 DINNERSTEIN A.J. & WOLFE M. TACTILE SLIT SCANNING OF LETTERS. PERCEPTUAL & MOTOR SKILLS, VOL 15, 1962, PP 135-138.

49 DOUCE J.L. & GILL J.M. COMPUTER-DRAWN MAPS FOR THE BLIND. ELECTRONICS & POWER, VOL 19, NO. 14, AUGUST 1973, PP 331-332.

50 DUPRESS J.K. BRAILLE RESEARCH AND DEVELOPMENT: PROGRESS AND PREDICTIONS. INT. J. FOR THE EDUC. OF THE BLIND, VOL 15, PT 3, MARCH 1966, PP 74-78.

51 DUNN L.M. & VERGASON G.A. EFFECTS OF ILLUSTRATION SIZE ON TEST PERFORMANCE. UNPUBLISHED MANUSCRIPT, GEORGE PEABODY COLLEGE FOR TEACHERS, 1961.

52 EKMAN G., LINDMAN R. & WILLIAM-OLGSON W. A PSYCHO-PHYSICAL STUDY OF CARTOGRAPHIC SYMBOLS. PERCEPTUAL & MOTOR SKILLS, DEC 1961, P 355.

53 EWART A.G. & CARP F.M. RECOGNITION OF TACTUAL FORM BY SIGHTED AND BLIND SUBJECTS. AMERICAN JOURNAL OF PSYCHOLOGY, VOL 76, NO. 3, 1963.

54 FENCHAK R. THE USE OF PRE-RECORDED CASSETTE TAPES AS AN ORIENTATION DEVICE IN MOBILITY TRAINING. UNPUBLISHED PAPER, UNIVERSITY OF PITTSBURGH, 1971.

55 FILLIPOV A.V. THE ADEQUACY OF PASSIVE TACTUAL PERCEPTION OF OBJECTS. VOPROSY PSIKHOLOGII, NO. 4, 1965, PP 103-110.

56 FITTS P.M. & SEEGER C.M. S-R COMPATABILITY: SPATIAL CHARACTERISTICS OF STIMULUS RESPONSE CODES. J. EXP. PSYCHOL., VOL 46, 1953, PP 199-210.

57 FLETCHER P. NOTES ON THE FUNCTION AND NATURE OF MODELS IN GEOGRAPHY TEACHING IN SCHOOLS FOR THE BLIND. TEACHER OF THE BLIND, VOL 46, NO. 2, JAN 1958, PP 39-44.

58 FLETCHER R.C. (ED) THE TEACHING OF SCIENCE AND MATHEMATICS TO THE BLIND (WITH SECTION ON RAISED DIAGRAMS). RNIB, LONDON, 1970, 154 PP.

59 FOULKE E. & MORRIS J.E. THE LEARNING AND RETENTION OF ASSOCIATIONS BETWEEN TACTILE STIMULI AND VERBAL RESPONSES. UNPUBLISHED, AMERICAN PRINTING HOUSE FOR THE BLIND, 1961.

60 FOULKE E. & WARM J. THE EFFECTS OF PATTERN COMPLEXITY AND REDUNDANCY ON TACTUAL RECOGNITION OF METRIC FIGURES. PERCEPTUAL AND MOTOR SKILLS, VOL 25, 1967, PP 177-187.

61 FOULKE E. THE PERCEPTUAL BASIS FOR MOBILITY. RESEARCH BULLETIN, NO. 23, JUNE 1971, PP 1-8.

62 FOULKE E. ANNUAL REPORT. UNIVERSITY OF LOUISVILLE, JUNE 1972.

63 FOSTER R.B. A TECHNIQUE FOR MAP-MAKERS. NEW BEACON, VOL 58, NO. 671, 1973.

64 FOX J.V.D. IMPROVING TACTILE DISCRIMINATION OF THE BLIND. AM. J. OF OCCUP. THERAPY, VOL 19, 1965, PP 5-7.

65 FRANKS F.L. & NOLAN C.Y. DEVELOPMENT OF GEOGRAPHICAL CONCEPTS IN BLIND CHILDREN. EDUCATION OF THE VISUALLY HANDICAPPED, VOL 2, 1970, PP 1-8.

66 FRANKS F.L. & BAIRD R.M. GEOGRAPHICAL CONCEPTS AND THE VISUALLY HANDICAPPED. EXCEPTIONAL CHILDREN, VOL 38, NO. 4, DEC 1971, PP 321-324.

67 FRANKS F.L. & BAIRD R.M. TEACHING GEOGRAPHICAL CONCEPTS TO YOUNG VISUALLY HANDICAPPED STUDENTS. UNPUBLISHED, AMERICAN PRINTING HOUSE FOR THE BLIND, 1971.

68 FRANKS F.L. & NOLAN C.Y. MEASURING GEOGRAPHICAL CONCEPT ATTAINMENT IN VISUALLY HANDICAPPED STUDENTS. EDUCATION OF THE VISUALLY HANDICAPPED, VOL 3, 1971, PP 11-17.

69 FROMM W. ZUR ARBEIT MIT RELIEFBILDERN BEI BLINDEN KINDERN. DIE SONDERSCHULE, VOL 1, JAN 1969, PP 47-52.

70 FULKER W.H. ILLUSTRATIONS AND EDUCATIONAL DEVICES FOR THE BLIND: IMPROVISIONS POSSIBLE AT SCHOOL LEVEL. PROC. AAIB, WATERTOWN, MASS., JUNE 1964, PP 58-59.

71 FULKER W.H. & FULKER M. TECHNIQUES WITH TANGIBLES. SPRINGFIELD, ILLINOIS, CHARLES C. THOMAS, 1967, 72 PP.

72 GARFINKEL M. TACTUAL THRESHOLDS IN CHILDREN AS A FUNCTION OF HANDEDNESS, SEX AND AGE. DISSERTATION ABSTRACTS, VOL 26, NO. 3496, 1965.

73 GARLAND C.W. METHODS OF PRODUCING EMBOSSED MATERIAL. NEW BEACON, VOL 56, NO. 658, FEB 1972, PP 33-35.

74 GARRY R. & ASCARELLI A. AN EXPERIMENT IN TEACHING TOPOGRAPHICAL ORIENTATION AND SPATIAL ORGANIZATION TO CONGENITALLY BLIND CHILDREN. WASHINGTON,D.C. U.S. OFFICE OF EDUCATION, 1960.

75 GARRY R.J. & ASCARELLI A. TEACHING TOPOGRAPHICAL ORIENTATION AND SPATIAL ORGANISATION TO CONGENITALLY BLIND CHILDREN. J. OF EDUCATION, VOL 143, 1960, PP 1-48.

76 GIBSON J.J. OBSERVATIONS ON ACTIVE TOUCH. PSYCHOLOGICAL REVIEW, VOL 69, 1962, PP 477-491.

77 GIBSON J.J. THE SENSES CONSIDERED AS PERCEPTUAL SYSTEMS. BOSTON, HOUGHTON MIFFLIN, 1966.

78 GILDEA R.Y. MAPS FOR THE BLIND. EXCEPTIONAL CHILDREN, VOL 22, 1956, P 340.

79 GILL J.M. TACTILE COMMUNICATION OF GRAPHICAL INFORMATION. MASTER'S THESIS, UNIVERSITY OF WARWICK, 1971.

80 GILL J.M. COMPUTER PRODUCTION OF TACTILE DIAGRAMS AND MAPS. THE LEONARD CONFERENCE, CAMBRIDGE, ENGLAND, JAN 1972, PP 73-77.

81 GILL J.M. PRACTICAL ASPECTS OF MAP PRODUCTION. MOBILITY MAP CONF, NOTTINGHAM, ENGLAND, SEPT 1972.

82 GILL J.M. A METHOD FOR THE PRODUCTION OF TACTUAL MAPS AND DIAGRAMS. RESEARCH BULLETIN, NO. 26, JUNE 1973, PP 203-204.

83 GILL J.M. & JAMES G.A. A STUDY ON THE DISCRIMINABILITY OF TACTUAL POINT SYMBOLS. RESEARCH BULLETIN, NO. 26, JUNE 1973, PP 19-34.

84 GILL J.M. & JAMES G.A. MOBILITY MAPS: THE CHOICE OF SYMBOLS. NEW BEACON, TO BE PUBLISHED.

85 GILL J.M. MOBILITY MAPS FOR THE BLIND. CENTRAL OFFICE OF INFORMATION, PROJECT, TO BE PUBLISHED.

86 GILMER B.V.H. PROBLEMS IN CUTANEOUS COMMUNICATION FROM PSYCHOPHYSICS TO INFORMATION PROCESSING. AMERICAN FOUNDATION FOR THE BLIND, NEW YORK, STATE OF THE ART REPORT, MARCH 1966.

87 GILSON C., WURZBURGER B. & JOHNSON D.E. THE USE OF THE RAISED MAP IN TEACHING MOBILITY TO BLIND CHILDREN. NEW OUTLOOK FOR THE BLIND, VOL 59, NO. 2, FEB 1965, PP 59-62.

88 GOLDISH L.H. THE VISUALLY IMPAIRED POPULATION AS A MARKET FOR SENSORY AIDS AND SERVICES: AIDS AND SERVICES FOR THE PARTIALLY SIGHTED. AMERICAN FOUNDATION FOR THE BLIND, 1973.

89 GOLLIN E.S. TACTUAL FORM DISCRIMINATION: A DEVELOPMENTAL COMPARISON UNDER CONDITIONS OF APATIAL INTERFERENCE. J. EXPTL. PSYCHOL., VOL 60, AUG 1960, PP 126-129.

90 GOLLIN E.S. TACTILE FORM DISCRIMINATION: DEVELOPMENTAL DIFFERENCES IN THE EFFECTS OF TRAINING UNDER CONDITIONS OF SPATIAL INTERFERENCE. J.PSYCHOL. VOL 51, 1961, PP 131-140.

91 GOMULICKI B.R. THE DEVELOPMENT OF PERCEPTION AND LEARNING IN BLIND CHILDREN. THE PSYCHOLOGICAL LAB., CAMBRIDGE UNIVERSITY.

92 GOODNOW J. EYE AND HAND: DIFFERENTIAL SAMPLING OF FORM AND ORIENTATION PROPERTIES. NEUROPSYCHOLOGIA, VOL 7, 1969, PP 365-373.

93 GRAY P.C. & TODD J.E. MOBILITY AND READING HABITS OF THE BLIND. HMSO, LONDON, 1968.

94 GREAT BRITAIN. DEPARTMENT OF EDUCATION AND SCIENCE. THE EDUCATION OF THE VISUALLY HANDICAPPED: REPORT OF THE COMMITTEE OF ENQUIRY APPOINTED BY THE SECRETARY OF STATE FOR EDUCATION AND SCIENCE IN OCTOBER 1968. (CHAIRMAN: M.D.VERNON). HMSO, 1972.

95 GREENBERG G.L. MAP DESIGN FOR PARTIALLY SEEING STUDENTS; AN INVESTIGATION OF WHITE VERSUS BLACK LINE SYMBOLOGY. DOCTORAL DISSERTATION, UNIVERSITY OF WASHINGTON, 1968.

96 GREENBERG G.L. & SHERMAN J.C. DESIGN OF MAPS FOR PARTIALLY SEEING CHILDREN. 1970 INTERNATIONAL YEARBOOK OF CARTOGRAPHY, PP 111-115.

97 GROVES P.A. & WIEDEL J.W. TACTUAL MAPPING: PROBLEMS OF DESIGN & INTERPRETATION INTERNATL. JOURNAL OF EDUCATION FOR THE BLIND, VOL 18, NO 1, MARCH 1968, PP 10-16.

98 HABY G. A STUDY ON THE VISUAL INTERPRETATION OF TACTUAL IMAGES. REVIEW OF PHILOSOPHY, VOL 31, 1931, PP 395-477.

99 HALLENBECK C.E. COMPUTER DISPLAYS AS OCCUPATIONAL AIDS FOR THE BLIND: PRELIMINARY REPORT ON RESEARCH IN PROGRESS. RESEARCH BULLETIN, AMERICAN FOUNDATION FOR THE BLIND, NO. 19, JUNE 1969, PP 248-251.

100 HARDCASTLE L. TEACHING OF GEOGRAPHY TO BLIND CHILDREN. NEW BEACON, NOV 1940, PP 218-220.

101 HARDCASTLE L. MAPS FOR THE BLIND. NEW BEACON, SEPT 1943, PP 157-159; OCT 1943, PP 185-186; NOV 1943, PP 208-210; DEC 1943, PP 224-225; JAN 1944, PP 14-16; FEB 1944, PP 32-33.

102 HATWELL Y. PERCEPTION TACTILE DES FORMES ET ORGANISATIONS SPATIALE TACTILE. (TACTILE FORM PERCEPTION IN THE ORGANISATION OF TACTILE SPACE). JOURNAL DE PSYCHOLOGIE NORMALE ET PATHOLOGIQUE, VOL 56, 1959, PP 187-204.

103 HATWELL Y. ETUDE DE QUELQUES ILLUSIONS GEOMETRIQUES TACTILES CHEZ LES AVEUGLES (A STUDY OF GEOMETRICAL TACTILE ILLUSIONS AMONG THE BLIND). ANNEE PSYCHOLOGIQUE, NO. 1, 1960, PP 11-27.

104 HATWELL Y. LA PERCEPTION TACTILE DES FORMES GEOMETRIQUES: PERCEPTION ET ACTIVITE PERCEPTIVE. (TACTILE PERCEPTION OF GEOMETRIC FORMS: PERCEPTION AND PERCEPTIVE ACTIVITY). JOURNAL DE PSYCHOLOGIE NORMALE ET PATHOLOGIQUE, VOL 57, 1960, PP 165-176.

105 HAYES S.P. THE MEMORY OF BLIND CHILDREN. TEACHERS FORUM, VOL 8, NO. 3, 1936, PP 55-59 & 71-74.

106 HEATH W.R. MAPS AND GRAPHS FOR THE BLIND: SOME ASPECTS OF THE DISCRIMINABILITY OF TEXTURAL SURFACES FOR USE IN AREAL DIFFERENTIATION. UNPUBLISHED DOCTORAL DISSERTATION, UNIVERSITY OF WASHINGTON, 1958.

107 HEATH W.R. & SHERMAN J.C. INVESTIGATION OF PROBLEMS IN THE PREPARATION OF TACTUAL MAPS FOR THE BLIND. PAPER PRESENTED AT THE 54TH ANNUAL MEETING OF THE ASSOCIATION OF AMERICAN GEOGRAPHERS, LOS ANGELES, CALIFORNIA, AUGUST 1958.

108 HOOPER M.S. ILLUSTRATIONS AND EDUCATIONAL DEVICES FOR THE BLIND: ILLUSTRATIONS IN MASS-PRODUCED BRAILLE BOOKS. PROC. AAIB, WATERTOWN, MASS., JUNE 1964, PP 60-63.

109 HUGHES J.R. & PRICE P.G. REPORT ON MOBILITY MAP CONFERENCE. MOBILITY OF THE BLIND ASSOC. NEWSLETTER, NO. 17, OCT 1972, PP 3-11.

110 IERIDES N.M. MAPS AND MODELS FOR THE BLIND. 1958 DISSERTATION ABSTRACTS.

111 JAMES B.F. TACTILE DISCRIMINATION IN YOUNG CHILDREN. UNPUBLISHED PH.D. THESIS, FLORIDA STATE UNIVERSITY, 1965.

112 JAMES G.A. PROBLEMS IN THE STANDARDISATION OF DESIGN AND SYMBOLISATION IN TACTILE ROUTE MAPS FOR THE BLIND. NEW BEACON, VOL 56, NO. 660, APRIL 1972, PP 87-91.

113 JAMES G.A. & GILL J.M. RECENT DEVELOPMENTS IN THE PRODUCTION AND DESIGN OF TACTUAL MAPS AND DIAGRAMS IN THE UNITED KINGDOM. ICEBY, MADRID, 1972.

114 JAMES G.A. SEQUENTIAL MAPS: VERBAL. MOBILITY MAP CONF, NOTTINGHAM, ENGLAND, SEPT 1972.

115 JAMES G.A. DESIGN FACTORS IN MAP PRODUCTION. MOBILITY MAP CONF, NOTTINGHAM, ENGLAND, SEPT 1972.

116 JAMES G.A. & GILL J.M. A PILOT STUDY ON THE DISCRIMINABILITY OF TACTILE AREAL AND LINE SYMBOLS FOR THE BLIND. RESEARCH BULLETIN, TO BE PUBLISHED.

117 JAMES G.A., CAMPBELL D.W. & ARMSTRONG J.D. VERBAL DESCRIPTIONS USED BY MOBILITY TEACHERS TO GIVE NAVIGATIONAL DIRECTIONS TO THEIR CLIENTS. NEW BEACON, VOL 56, NO. 672, MAY 1973, PP 86-91.

118 JAMES G.A. & GILL J.M. 'MOBILITY MAPS' FOR THE VISUALLY HANDICAPPED: A STUDY OF LEARNING AND RETENTION OF RAISED SYMBOLS. RESEARCH BULLETIN, TO BE PUBLISHED.

119 JAMES W.R.K. THE TACTILE PERCEPTION AND CONCEPT FORMING OF BLIND CHILDREN. TEACHER OF THE BLIND, VOL 53, NO. 1, OCT 1964.

120 JAMES W.R.K. SYSTEMS OF ILLUSTRATION FOR THE VISUALLY HANDICAPPED; PSYCHOLOGICAL PRINCIPLES OF DESIGN AND USAGE. THE LEONARD CONFERENCE, CAMBRIDGE, ENGLAND, JAN 1972, PP 78-84.

121 JAMES W.R.K. MAP MAKING AND THINKING. MOBILITY MAP CONF, NOTTINGHAM, ENGLAND, SEPT 1972.

122 JANSSON G. SYMBOLS FOR TACTILE MAPS. IN LINDQVIST B. & TROWALD N. (EDS) EUROPEAN CONFERENCE OF EDUCATIONAL RESEARCH FOR THE VISUALLY HANDICAPPED. PROJECT PUSS: V111. REPORT NO. 31 1972. PP 66-73.

123 JENKINS W.O. THE TACTUAL DISCRIMINATION OF SHAPES FOR CODING AIRCRAFT-TYPE CONTROLS. IN P.M.FITTS (ED), PSYCHOLOGICAL RESEARCH ON EQUIPMENT DESIGN, WASHINGTON D.C., U.S. GOVT. PRINTING OFFICE, 1947, PP 119-205.

124 JOHNSON H.D. MAP-WORK IN THE ELEMENTARY GRADES. PROC. 38TH MTG AAIB, WATERTOWN, MASS., 1946.

125 KIDWELL A.M. & GREER P.S. ENVIRONMENTAL PERCEPTIONS OF THE BLIND AND THEIR HAPTIC REPRESENTATION. M.A. THESIS, SCHOOL OF ARCHITECTURE, M.I.T., JUNE 1972.

126 KIDWELL A.M. & GREER P.S. THE ENVIRONMENTAL PERCEPTIONS OF BLIND PERSONS AND THEIR HAPTIC REPRESENTATION. NEW OUTLOOK, VOL 66, NO. 8, OCT 1972, PP 256-276.

127 KOOYMAN W.J.J. PERMANENT EDUCATION OF MOBILITY IN ALL ITS ASPECTS. MOBILITY MAP CONF, NOTTINGHAM, ENGLAND, SEPT 1972.

128 KREBS B.M. ILLUSTRATIONS AND EDUCATIONAL DEVICES FOR THE BLIND: DEVELOPMENT OF STANDARDS FOR EMBOSSED ILLUSTRATIONS. PROC. AAIB, WATERTOWN, MASS., JUNE 1964, PP 67-68.

129 LANDIS D. & SLIVKA R.M. DISPLAYS FOR DECISION MAKING. INT. J. PROD. RES., VOL 10, NO. 3, JULY 1972, PP 215-229.

130 LEONARD J.A. EXPERIMENTAL MAPS FOR BLIND TRAVEL. NEW BEACON, VOL 50, NO. 586 1966, PP 32-35.

131 LEONARD J.A. AIDS TO NAVIGATION; A DISCUSSION OF THE PROBLEMS OF MAPS FOR BLIND TRAVELLERS. CONF. ON SENSORY DEVICES FOR THE BLIND, ST DUNSTANS, LONDON, 1967.

132 LEONARD J.A. MOBILITY AS A SCHOOL SUBJECT. TEACHER OF THE BLIND, VOL 55, 1967, PP 102-107.

133 LEONARD J.A. & NEWMAN R.C. SPATIAL ORIENTATION IN THE BLIND. NATURE, VOL 215, 1967, PP 1413-1414.

134 LEONARD J.A. A SUGGESTED SYLLABUS FOR MAP READING TEACHING FOR BLIND YOUNGSTERS. UNPUBLISHED, 1968.

135 LEONARD J.A. & WYCHERLEY R.J. TOWARDS THE MEASUREMENT OF PERFORMANCE OF TRAVEL SKILL. CONF. MOBILITY TRAINERS & TECHNOLOGISTS, AFB, NEW YORK, 1968.

136 LEONARD J.A. MODERN TRENDS IN MOBILITY. RESEARCH BULLETIN, NO. 19, JUNE 1969, PP 73-89.

137 LEONARD J.A. & NEWMAN R.C. A COMPARISON OF THREE TYPRES OF PORTABLE ROUTE 'MAPS' FOR BLIND TRAVEL. BULL. BRIT. PSYCHOL. SOC., VOL 21, 1969.

138 LEONARD J.A. ACCOUNT OF A RESEARCH PROGRAMME INTO MOBILITY. NATO ADVANCED STUDY INSTITUTE HUMAN FACTORS / ERGONOMICS, MONDELLO, SICILY, AUTUMN 1969.

139 LEONARD J.A. & NEWMAN R.C. THREE TYPES OF 'MAPS' FOR BLIND TRAVEL. ERGONOMICS, VOL 13, NO. 2, MARCH 1970, PP 165-179.

140 LEONARD J.A. THE CONCEPT OF THE MINIMAL INFORMATION REQUIRED FOR EFFECTIVE MOBILITY AND SUGGESTIONS FOR FUTURE NON-VISUAL DISPLAYS. . EVALUATION OF MOBILITY AIDS FOR THE BLIND, WARRENTON, VIRGINIA, JUNE 1970.

141 LEONARD J.A. BLIND MOBILITY: THE STATE OF THE ART IN NAVIGATION AND ORIENTATION. UNPUBLISHED, UNIVERSITY OF NOTTINGHAM, AUGUST 1971.

142 LISSAU R. TEACHING GEOGRAPHY TO BLIND CHILDREN. NEW BEACON, AUG 1940, PP 160-162; SEPT 1940, PP 182-183; OCT 1940, PP 194-195.

143 MAGLIONE F.D. AN EXPERIMENTAL STUDY OF THE USE OF TACTUAL MAPS AS ORIENTATION AND MOBILITY AIDS FOR ADULT BLIND SUBJECTS. PH.D. THESIS, UNIVERSITY OF ILLINOIS, 1969, 145P.

144 MAJOR D.R. CUTANEOUS PERCEPTION OF FORM. AMER. J. OF PSYCHOL., VOL 10, 1898, PP 143-147.

145 MALLINSON G. & MALLINSON J. SYMBOLIC SCIENCE LEARNING FOR THE BLIND. SCHOOL SCIENCE & MATHEMATICS, MAY 1967, PP 432-449.

146 MANDOLA J. A THEORETICAL APPROACH TO GRAPHIC AIDS FOR THE BLIND. INTERNATL. JOURNAL OF EDUCATION FOR THE BLIND, VOL 18, NO. 1, MARCH 1968, PP 20-24.

147 MERRY F.K. A FURTHER INVESTIGATION TO DETERMINE THE VALUE OF EMBOSSED PICTURES FOR BLIND CHILDREN. TEACHERS FORUM, VOL 4, 1932, PP 96-99.

148 MERRY R.V. TO WHAT EXTENT CAN BLIND CHILDREN RECOGNIZE TACTUALLY SIMPLE EMBOSSED PICTURES? TEACHERS FORUM, VOL 3, 1930, PP 2-5.

149 MERRY R.V. & MERRY F.K. THE TACTUAL RECOGNITION OF EMBOSSED PICTURES BY BLIND CHILDREN. J. OF APPLIED PSYCHOLOGY, VOL 17, 1933, PP 148-163.

150 MEYERS E. JULY PROGRESS REPORT. UNPUBLISHED REPORT, AMERICAN PRINTING HOUSE FOR THE BLIND, 1955.

151 MEYERS E., ETHINGTON D. & ASHCROFT S. READABILITY OF BRAILLE AS A FUNCTION OF THREE SPACING VARIABLES. J. OF APPL. PSYCHOL., VOL 42, 1958, PP 163-165.

152 MOORE T.J. A SELECTIVE REVIEW OF THE LITERATURE ON TACTILE SENSITIVITY: 1940-1965. REPORT N67-11922. AD 638 718, APRIL 1966.

153 MORRIS J.E. DISCRIMINABILITY OF TACTUAL PATTERNS. MASTER'S THESIS, UNIVERSITY OF LOUISVILLE, 1960.

154 MORRIS J.E. & FOULKE E. THE LEARNING AND RETENTION OF ASSOCIATIONS BETWEEN PAIRS OF TACTUAL AND AUDITORY STIMULI. UNPUBLISHED, AMERICAN PRINTING HOUSE FOR THE BLIND, 1960.

155 MORRIS J.E. & NOLAN C.Y. DISCRIMINABILITY OF TACTUAL PATTERNS. INTERNATL. J. FOR THE EDUCATION OF THE BLIND, VOL 11, NO. 2, DEC 1961, PP 50-54.

156 MORRIS J.E. & NOLAN C.Y. MINIMUM SIZES FOR AREAL TYPE TACTUAL SYMBOLS. INTERNATL. J. FOR THE EDUCATION OF THE BLIND, VOL 13, NO. 2, DEC 1963, PP 48-51.

157 MORRIS J.E. & NOLAN C.Y. MATERIALS AND TECHNIQUES FOR STUDY: A CONSUMER SURVEY EDUCATION OF THE VISUALLY HANDICAPPED, VOL 1, 1969, PP 8-11.

158 MORRIS J.E. & NOLAN C.Y. BIBLIOGRAPHY OF RESEARCH ON THE VISUALLY HANDICAPPED 1953 - 1971. AMERICAN PRINTING HOUSE FOR THE BLIND, 1972.

159 MUELLER M.W. EFFECTS OF ILLUSTRATION SIZE ON TEST PERFORMANCE OF VISUALLY LIMITED CHILDREN. EXCEPTIONAL CHILDREN, VOL 29, 1962, PP 124-128.

160 MUMFORD D.O. THE LEICESTER MAP PROJECT. NEW BEACON, VOL 56, NO. 665, SEPT 1972, PP 231-233.

161 MUMFORD D.O. SEQUENTIAL MAPS: TACTILE. MOBILITY MAP CONF, NOTTINGHAM, ENGLAND, SEPT 1972.

162 MUMFORD D.O. URBAN MAPPING. MOBILITY MAP CONF, NOTTINGHAM, ENGLAND, SEPT 1972.

163 MYRBERG M. METHODS FOR CONVEYING GRAPHICAL INFORMATION TO THE VISUALLY HANDICAPPED. IN LINDQVIST B. & TROWALD N. (EDS) EUROPEAN CONFERENCE OF EDUCATIONAL RESEARCH FOR THE VISUALLY HANDICAPPED. PROJECT PUSS: V111. REPORT NO. 31 1972. PP 59-65.

164 MYRBERG M. DIREKTIV INFORMATION I LAROMEDEL. UNIVERSITY OF UPPSALA, 1972.

165 MYRBERG M. VISUALISERING AV LAROBOCKER OCH STUDIELITTERATUR FOR SYNSKADADE. UNIVERSITY OF UPPSALA, 1972.

166 MCREYNOLDS J. & WERCHEL P. GEOGRAPHIC ORIENTATION IN THE BLIND. JOURNAL OF GENERAL PSYCHOLOGY, VOL 51, 1954, PP 221-236.

167 NOLAN C.Y. ROUGHNESS DISCRIMINATION AMONG BLIND CHILDREN IN THE PRIMARY GRADES INT. J. FOR THE EDUCATION OF THE BLIND, VOL 9, 1960, PP 97-100.

168 NOLAN C.Y. & MORRIS J.E. FURTHER RESULTS IN THE DEVELOPMENT OF A TEST OF ROUGHNESS DISCRIMINATION. INT. J. FOR THE EDUCATION OF THE BLIND, VOL 10, 1960, PP 48-50.

169 NOLAN C.Y. A STUDY OF PICTURES FOR LARGE TYPE TEXTBOOKS. INT. J. FOR THE EDUC. OF THE BLIND, VOL 9, 1960, PP 67-70.

170 NOLAN C.Y. LEGIBILITY OF INK AND COLOR COMBINATIONS FOR READERS OF LARGE TYPE. INT. J. FOR THE EDUC. OF THE BLIND, VOL 10, 1961, PP 82-84.

171 NOLAN C.Y. TEACHER PREFERENCE FOR TYPES OF ILLUSTRATIONS IN LARGE TYPE BOOKS. INT. J. FOR THE EDUC. OF THE BLIND, VOL 10, 1961, PP 112-114.

172 NOLAN C.Y. & MORRIS J.E. RESEARCH ON THE PARTIALLY SIGHTED. UNPUBLISHED, AMERICAN PRINTING HOUSE FOR THE BLIND.

173 NOLAN C.Y. CUES IN THE TACTUAL PERCEPTION OF PATTERNS: PROGRESS REPORT. AMERICAN PRINTING HOUSE FOR THE BLIND, 1962.

174 NOLAN C.Y. & MORRIS J.E. TACTUAL SYMBOLS FOR THE BLIND: FINAL REPORT. OVR-RD-587, AMERICAN PRINTING HOUSE FOR THE BLIND, LOUISVILLE, 1963.

175 NOLAN C.Y. PERCEPTUAL PROBLEMS IN THE USE OF ILLUSTRATIVE MATERIALS. PROC. AAIB, WATERTOWN, MASS., JUNE 1964.

176 NOLAN C.Y. & MORRIS J.E. ROUGHNESS DISCRIMINATION TEST MANUAL. LOUISVILLE, KENTUCKY: APH, 1965.

177 NOLAN C.Y. & MORRIS J.E. IMPROVEMENT OF TACTUAL SYMBOLS FOR BLIND CHILDREN. REPORT OF DEPT. OF HEALTH, EDUCATION, AND WELFARE. PROJECT NO. 5-0421,1971

178 NOLAN C.Y. RELATIVE LEGIBILITY OF RAISED AND INCISED TACTUAL FIGURES. EDUCATION OF THE VISUALLY HANDICAPPED, VOL 3, 1971, PP 33-36.

179 ORGROSKY C.E. NEW APPROACHES TO THE PREPARATION AND REPRODUCTION OF TACTUAL AND ENHANCED IMAGE GRAPHICS FOR THE VISUALLY HANDIVAPPED. MASTER'S THESIS, UNIVERSITY OF WASHINGTON, 1973.

180 PAGE F. MAPS FOR THE BLIND. SCHOOL TECHNOLOGY, VOL 5(4), BULLETIN 22, JUNE 1972, PP 30-32.

181 PEARCE B.D. TACTILE DISCRIMINATION AND MANUAL DEXTERITY IN BLIND CHILDREN. DISSERTATION, UNIVERSITY OF BIRMINGHAM, 1959, 93 PP.

182 PICK A.D. IMPROVEMENT OF VISUAL AND TACTUAL FORM DISCRIMINATIONS. J. EXPTL. PSYCHOL., VOL 69, APRIL 1965, PP 331-339.

183 PICK A.D. & PICK H.L. A DEVELOPMENTAL STUDY OF TACTUAL DISCRIMINATION IN BLIND AND SIGHTED CHILDREN AND ADULTS. PSYCHONOMIC SCIENCE, VOL 6, 1966, PP 367-368.

184 PICK H.L., KLEIN R.E. & PICK A.D. VISUAL AND TACTUAL IDENTIFICATION OF FORM ORIENTATION. J. OF EXPTL. CHILD PSYCHOL., VOL 4, 1966, PP 391-397.

185 PICKLES W.J. TEACHING OF SCIENCE TO THE BLIND. PROC. ICEBY, WATERTOWN, MASS., 1967, PP 219-222.

186 PICKLES W.J. MAP USAGE BY GRAMMAR SCHOOL PUPILS. MOBILITY MAP CONF, NOTTINGHAM, ENGLAND, SEPT 1972.

187 PRATT C.L. PRACTICAL GEOGRAPHY FOR THE BLIND. PERKINS SCHOOL FOR THE BLIND, WATERTOWN, MASS., 1937.

188 RAPPAPORT M. THE ROLE OF REDUNDANCY IN THE DISCRIMINATION OF VISUAL FORMS. J. EXP. PSYCHOL., VOL 53, 1957, PP 3-10.

189 REVESZ G. PSYCHOLOGY AND ART OF THE BLIND. LONGMANS, 1950.

190 SAAB-SCANIA HANDICAP EQUIPMENT: RELIEF PRINTER SAAB EPP 370. SAAB, SWEDEN, 1972.

191 SAUNDERS M. WORKS ON BLINDNESS AND ASSOCIATED SUBJECTS. RNIB, LONDON, 1971.

192 SCHAROFF V. ILLUSTRATIONS AND EDUCATIONAL DEVICES FOR THE BLIND. PROC. AAIB, WATERTOWN, MASS., JUNE 1964, PP 64-66.

193 SCHEEL J. ELECTRONIC TRACER. J.SCHEEL LTD, GERMANY, 1969.

194 SCHIFF W. RESEARCH ON RAISED LINE DRAWINGS. NEW OUTLOOK FOR THE BLIND. VOL 59, NO. 4, APRIL 1965, PP 134-137.

195 SCHIFF W. & ISIKOW H. STIMULUS REDUNDANCY IN THE TACTILE PERCEPTION OF HISTOGRAMS. INTERNATL. J. FOR THE EDUCATION OF THE BLIND, VOL 16, NO. 1, OCT 1966, PP 1-11.

196 SCHIFF W. MANUAL FOR THE CONSTRUCTION OF RAISED LINE DIAGRAMS. NOV 1966.

197 SCHIFF W., KAUFER L. & MOSAK S. INFORMATIVE TACTILE STIMULI IN THE PERCEPTION OF DIRECTION. PERCEPTUAL AND MOTOR SKILLS, VOL 23 (MONOGR. SUPPL. 7), 1966

198 SCHIFF W. USING RAISED LINE DRAWINGS AS TACTUAL SUPPLEMENTS TO RECORDED BOOKS FOR THE BLIND. FINAL REPORT, RD-1571-S, RECORDINGS FOR THE BLIND, NEW YORK, JUNE 1967.

199 SCHIFF W. & DYTELL R.S. TACTILE IDENTIFICATION OF LETTERS: A COMPARISON OF DEAF AND HEARING CHILDREN'S PERFORMANCES. J. OF EXPERIMENTAL CHILD PSYCHOLOGY, VOL 11, NO. 1, FEB 1971, PP 150-164.

200 SCHIFF W. & DYTELL R.S. DEAF AND HEARING CHILDREN'S PERFORMANCE ON A TACTUAL PERCEPTION BATTERY. PERCEPTUAL & MOTOR SKILLS, VOL 35, MONOGRAPH SUPPL. 2-V35, 1972, PP 683-706.

201 SEDDON J. AN EXPERIMENT TO INVESTIGATE THE HAPTIC PERCEPTION OF BLIND CHILDREN AND THEIR ABILITY TO INTERPRET RAISED LINE DRAWINGS. DISSERTATION, UNIVERSITY OF BIRMINGHAM, 1967, 62 PP.

202 SHAW A. PRINT FOR PARTIAL SIGHT. THE LIBRARY ASSOCIATION, LONDON, 1969,92 PP

203 SHEPHERD C. MAP WORK WITH BLIND STUDENTS. PROC. ICEBY, WATERTOWN, MASS., 1967, PP 240-241.

204 SHERMAN J.C. MAPS THE BLIND CAN SEE. JOURNAL OF GEOGRAPHY, VOL 56, SEPT 1955 PP 289-295.

205 SHERMAN J.C. & HEATH W.R. PROBLEMS IN DESIGN AND PRODUCTION OF MAPS FOR THE BLIND. SECOND INTERNATNL. CARTOGRAPHIC CONF., SERIES II, (3) 1959, PP 52-59.

206 SHERMAN J.C. CURRENT MAP RESOURCES AND EXISTING MAP NEEDS FOR THE BLIND. SURVEYING AND MAPPING, VOL 24, 1964, PP 611-616.

207 SHERMAN J.C. NEEDS AND RESOURCES IN MAPS FOR THE BLIND. NEW OUTLOOK FOR THE BLIND, VOL 59, NO. 4, APRIL 1965, PP 130-134. REPRINTED IN THE EDUCATOR, NO. 4, DEC 1965.

208 SLEIGHT R.B. THE RELATIVE DISCRIMINABILITY OF SEVERAL GEOMETRIC FORMS. J. EXPERIMENTAL PSYCHOLOGY, VOL 43, 1952, PP 324-328.

209 SZUMAN W. O DOSTEPNOSCI RYSUNKU DLA DZIECI NIEWIDOMYCH. PZWS, WARSAW, 1967.

210 TOBIN M.J. REPORT ON OVERSEAS RESEARCH. TEACHER OF THE BLIND, VOL 59, NO. 3, APRIL 1971, PP 117-126 AND VOL 59, NO. 4, 1971, PP 154-170.

211 TOOZE D.W. USE OF MOBILITY MAPS IN THE EDUCATION OF THE BLIND CHILD. MOBILITY MAP CONF, NOTTINGHAM, ENGLAND, SEPT 1972.

212 TOOZE F.H.G. MOBILITY TRAINING IN SCHOOLS FOR THE VISUALLY HANDICAPPED. TEACHER OF THE BLIND, VOL 60, NO. 1, OCT 1971, PP 11-47.

213 TRAYLOR D.R. THE HUEGEL QUILL: A NEW TACTILE DEVELOPMENT FOR THE BLIND. PROC. 1972 CARNAHAN CONFERENCE ON ELECTRONIC PROSTHETICS, UNIVERSITY OF KENTUCKY, PP 147-149.

214 VAUGHT G.M. FORM DISCRIMINATION AS A FUNCTION OF SEX, PROCEDURE AND TACTUAL MODE. PSYCHONOMIC SCIENCE, VOL 10, 1968, PP 151-152.

215 VERMEY G.J. OBSERVATIONS ON RAISED-LINE DRAWINGS. EDUCATION OF THE VISUALLY HANDICAPPED, VOL 1, NO. 2, MAY 1969, PP 47-52.

216 VINCENT C.N. TEACHING THE BLIND TO DRAW. INDUSTRIAL & SCIENTIFIC COMMUNICATION, VOL 1, NO. 6, JUNE 1970.

217 WARM J. & FOULKE E. EFFECTS OF ORIENTATION AND REDUNDANCY ON TACTUAL PERCEPTION OF FORM. PERCEPTUAL & MOTOR SKILLS, VOL 27, 1968, PP 83-89.

218 WARM J., CLARK J.L. & FOULKE E. EFFECTS OF DIFFERENTIAL SPATIAL ORIENTATION ON TACTUAL PATTERN RECOGNITION. PERCEPTUAL AND MOTOR SKILLS, VOL 31, 1970, PP 87-94.

219 WESTOVER A. RELIEF MAP OF CAMPSUS. OUTLOOK FOR THE BLIND AND TEACHERS FORUM, VOL 41, SEPT 1947, PP 191-193.

220 WEXLER A. EXPERIMENTAL SCIENCE FOR THE BLIND. PERGAMON PRESS, 1961, 97 PP.

221 WEXLER A. SHAPE RECOGNITION AND DRAWING BY THE BLIND PARTS I & II. NEW BEACON, VOL 49, NO. 581, SEPT 1965, PP 228-233; NO. 582, OCT 1965, PP 254-258.

222 WEXLER A. GEOMETRY FOR BLIND STUDENTS. NEW BEACON, VOL 50, NO. 588, APRIL 1966, PP 86-91.

223 WITCHER C.M. RAISED LINE DRAWING FOR THE BLIND - A NEW SOLUTION TO THE PROBLEM. OUTLOOK FOR THE BLIND AND TEACHERS FORUM, VOL 43, APRIL 1949, PP 101-104.

224 WHITTAKER J. GRAPHICAL REPRESENTATION. TEACHER OF THE BLIND, VOL 56, NO. 1, OCT 1967.

225 WIEDEL J.W. VIRKOTYPE PROCESS OF RAISED PRINTING. CIRCULAR 64-10 DIVISION FOR THE BLIND, LIBRARY OF CONGRESS, OCT 1964.

226 WIEDEL J.W. PROBLEMS IN DEVELOPING GRAPHICS FOR THE BLIND. PAPER PRESENTED AT THE 61 ST ANNUAL MEETING OF THE ASSOC. OF AMER. GEOGRAPHERS, COLUMBUS, OHIO, 21 APRIL 1965.

227 WIEDEL J.W. TACTUAL MAPS FOR THE VISUALLY HANDICAPPED, SOME DEVELOPMENTAL PROBLEMS. THE PROFESSIONAL GEOGRAPHER, VOL 18, NO. 3, MAY 1966, PP 132-139; AND NEW OUTLOOK, MARCH 1969, PP 80-88.

228 WIEDEL J.W. DEVELOPMENT AND STANDARDIZATION OF SYMBOLS AND IMPROVEMENT IN THE DESIGN OF TACTUAL ILLUSTRATIONS FOR THE BLIND. UNPUBLISHED, JULY 1967, 20 PP.

229 WIEDEL J.W. TACTUAL MAPPING: PROBLEMS OF DESIGN AND INTERPRETATION INTERNATL. J. FOR THE EDUCATION OF THE BLIND, MARCH 1968.

230 WIEDEL J.W. & GROVES P.A. MOBILITY-ORIENTATION MAPS FOR THE BLIND. RESEARCH GRANT NO. RD 2557-S-68-C1, SOCIAL REHABILITATION SERVICE, DEPT. OF HEALTH, EDUCATION AND WELFARE, WASHINGTON.

231 WIEDEL J.W. & GROVES P.A. DESIGNING AND PRODUCING TACTUAL MAPS FOR THE VISUALLY HANDICAPPED. NEW OUTLOOK, VOL 63, NO. 7, SEPT 1969, PP 196-201.

232 WIEDEL J.W. & GROVES P.A. TACTUAL MAPPING: DESIGN, REPRODUCTION, READING AND INTERPRETATION. FINAL REPORT RD-2557-S 1969, DEPT. OF HEALTH, EDUCATION, AND WELFARE. REPRINTED AS AN OCCASIONAL PAPER NO. 2, DEPT. OF GEOGRAPHY, UNIVERSITY OF MARYLAND, 1971.

233 WIEDEL J.W. & GROVES P.A. TOWARDS A TECHNIQUE FOR TACTUAL MAP DESIGN AND REPRODUCTION. SOCIETY OF UNIVERSITY CARTOGRAPHERS BULLETIN (LIVERPOOL), WINTER 1969-70, PP 12-18.

234 WIEDEL J.W. & GROVES P.A. MAPS AS SPECIALIZED MOBILITY AIDS FOR THE BLIND. PROC. ACSM-ASP TECHNICAL CONF., COLORADO, OCT 1970, PP 475-489.

235 WIEDEL J.W. & GROVES P.A. TACTUAL MAPS. 1970 INTERNATL YEARBOOK OF CARTOGRAPHY, PP 116-123.

236 WIEDEL J.W. PRE-PRINTED THERMOFORMED MOBILITY MAPS. UNPUBLISHED, UNIVERSITY OF MARYLAND, 1971, 7 PP.

237 WIEDEL J.W. REPRESENTATIONS ON TACTILE MAPS. MOBILITY MAP CONF, NOTTINGHAM, ENGLAND, SEPT 1972.

238 WINTERBOTTOM N.H. USABLE TACTILE MAPS FOR THE ADULT BLIND. MOBILITY MAP CONF NOTTINGHAM, ENGLAND, SEPT 1972.

239 WORCHEL P. SPACE PERCEPTION AND ORIENTATION IN THE BLIND. PSYCHOL. MONOGR. NO. 332, 1951.

240 YEAGER P. AUDITORY MAPPING FOR THE VISUALLY HANDICAPPED. UNPUBLISHED PAPER, UNIVERSITY OF PITTSBURGH, 1972.

241 ZAHL P.A. BLINDNESS: MODERN APPROACHES TO THE UNSEEN ENVIRONMENT. PRINCETON UNIVERSITY PRESS, 1950. REPRINT NEW YORK,HAFNER, 1962.

242 ZIGLER M.J. & BARRETT F. A FURTHER CONTRIBUTION TO THE TACTUAL PERCEPTION OF FORM. J. EXPTL. PSYCHOL., VOL 10, 1927, PP 184-192.

Appendix 5. Program CADEMD

Listing

Flowcharts

Operator's manual

Standard symbols

```
:28 OCT 04,'73
OB JMG,CADEMD
TTEND
LLOBT (FILE,OV),(FSI,200)
LLOBT (FILE,GO),(RSI,30),(FOR,B),(FSI,7CO),SAVE
ORTRANH GO,RT,LS
  EXTENDED FIV-H, VERSION DOO
C
C
C                       PROGRAM CADEMD
C
C
C      COMPUTER-AIDED DESIGN OF EMBOSSED MAPS AND DIAGRAMS
C
C
C          CHANNEL NUMBERS
C
C      2    TEMPORARY DISPLAY FILE ON DISK, AREA D3
C      5    PERMANENT SYMBOL DATA FILE ON DISK, AREA D1
C      10   VDU FOR DIRECT READ/WRITE STATEMENTS
C      125  PAPER-TAPE READER
C      128  PAPER-TAPE PUNCH
C
C
C          VARIABLES
C
C      IX,IY      CO-ORDINATES OF THE END POINTS OF LINES
C                 HELD IN THE DATA FILE IN UNITS OF .001 INS.
C      KX,KY      CO-ORDINATES OF THE DISPLAY IN RASTER UNITS
C      IA         HEIGHT OF EMBOSSING IN UNITS OF .001 INCHES
C      IB         LINE TYPE (SEE BELOW)
C      IC         GRADE 1 BRAILLE CODES
C      SF         DISPLAY SCALE FACTOR
C      XY         VOLTAGES FROM THE CO-ORDINATE TABLE
C      ILET       THE ALPHABET
C      NUM        THE NUMERALS
C      P          SCALE FACTOR FROM CO-ORDINATE TABLE
C      ICOR       MACRO NUMBER
C      THETA      ANGLE FROM THE HORIZONTAL FOR BRAILLE TEXT
C      KXD,KYD    RELATIVE DISPLAY ORIGIN
C      IBF        LAST VALUE OF IB
C      IS(1)      BRAILLE NUMBER FLAG
C      IS(2)      NUMBER OF LINES OF MESSAGES
C      IS(3)      MOVE FLAG
C      IS(4)      SYMBOL NUMBER
C      IS(5)      IANEXT FLAG
C      IS(6)      NUMBER OF POINTS FROM CO-ORDINATE TABLE
C      IS(7)      NUMBER OF CHARACTERS OF TEXT TO BE CONVERTED
C                 TO BRAILLE
C      IS(8)      JOB NUMBER
C      IS(9)      BRAILLE CELL SIZE
C      IS(10)     UNITS, INCHES OR METRIC
C      IS(11)     SYMBOL SIZE
C      IS(12)     SYMBOL QUADRANT
C      IS(13)     SCRATCH DATA FILE PROTECTION FLAG
C      IS(14)     MACRO FLAG
```

```
C
C
C        LINE TYPES (IB)
C
C     1          CONTINUOUS LINE
C     2          NO LINE, MOVE ONLY
C     3          POINT (BRAILLE DOT)
C     4          DOTTED LINE, SPACING 0.05 INCHES
C     5          DOTTED LINE, SPACING 0.15 INCHES
C     6          DOTTED LINE, SPACING 0.25 INCHES
C     7          DASHED LINE, SPACE 0.2 INS, DASH 0.2 INS
C     8          DASHED LINE, SPACE 0.1 INS, DASH 0.1 INS
C     9          END OF DATA
C     10         DASHED LINE, SPACE 0.3 INS, DASH 0.2 INS
C     11         DOT-DASH LINE, SPACE .1, LINE .2, SPACE .1
C                INCHES, DOT
C     12         DOT-DASH LINE, SPACE 0.2 INS, LINE 0.4 INS,
C                SPACE 0.2 INS, DOT
C
C
C
      COMMON /A/ IX,IY,KX,KY,IA,IB,IC(37),SF,XY(2),ILET(26),
     1NUM(10),P,ICOR,IS(15),THETA,KXD,KYD,IBF
C
      DATA ILET/'A','B','C','D','E','F','G','H','I','J',
     1'K','L','M','N','O','P','Q','R','S','T','U','V',
     2'W','X','Y','Z'/
      DATA NUM/'1','2','3','4','5','6','7','8','9','0'/
C
C     SET-UP GRADE 1 BRAILLE CODES
      DATA IC/100000,110000,100100,100110,100010,110100,
     1110110,110010,10100,10110,101000,111000,101100,
     2101110,101010,111100,111110,111010,11100,11110,
     3101001,111001,10111,101101,101111,101011,1111,
     410011,10010,11000,10000,1000,11011,1,1001,11001,0/
C
C     CONNECT INTERRUPTS TO SUBROUTINES
      CONNECT (2Z64,INNER)
      CONNECT (2Z65,JOYCON)
      CONNECT (2Z66,VDU)
      CONNECT (2Z67,I1)
      CONNECT (2Z68,I2)
      CONNECT (2Z6A,IANEXT(IS(5)))
C
C     DISABLE CO-ORDINATE TABLE INTERRUPTS
      CALL DISAB (2Z66,2Z67,2Z68)
C
C     INITIALISE VISUAL DISPLAY UNIT COMMUNICATION HANDLER
      CALL CSTOP (2)
      CALL CSTART (2,ISTAT)
      CALL CSET (2,132,0)
C
C     SET-UP DEFAULT VALUES
      J1=0
      J2=2
      WRITE (2,10) J1,J2,J1,J1
```

```
   10 FORMAT (4A4)
      IA=10
      IB=1
      SF=1.5
      ICOR=10
      THETA=0.0
      KXD=0
      KYD=0
      IS(4)=1
      IS(8)=0
      DO 20 I=1,6
   20 IS(8+I)=1
      IS(9)=2
      IS(11)=100
      P=25.0
C
C     SET VDU DISPLAY SCALE FACTOR TO UNITY
      CALL SCALE (0.0,0.0,1.0,1.0)
C
C     ERASE SCREEN OF VDU
      CALL ERASE
C
C     DISPLAY LIST OF COMMANDS ON RH SIDE OF SCREEN
      CALL LIST
C
C     DISPLAY CROSSWIRES
      CALL JOYSTIK (2Z65)
      STOP
      END
```

```
FORTRANH LS,GO
   EXTENDED FIV-H, VERSION D00
                         SUBROUTINE DELETE(N)
                   C
                   C     THIS SUBROUTINE DELETES LINES (N=1) OR MACROS (N=2).
                   C     THE ALGORITHM DETERMINES WHETHER THE POSITION OF THE
                   C     CROSSWIRES IS BETWEEN THE TWO END POINTS OF THE LINE
                   C     CURRENTLY BEING EXAMINED.  IT THEN CHECKS IF THE
                   C     GRADIENT IS THE SAME WITHIN A CERTAIN TOLERANCE.
                   C
                   C
                         COMMON /A/ IX,IY,KX,KY,IA,IB,IC(37),SF,XY(2),ILET(26),
                        1NUM(10),P,ICOR,IS(15),THETA,KXD,KYD,IBF
                   C
                   C     WRITE END OF DATA
                         ICOR=ICOR+1
                         IAB=IA*100+2
                         WRITE (2,100) ICOR,IAB,IX,IY
                         IT=9
                         WRITE (2,100) IT,IT,IT,IT
                         JX=0
                         JY=0
                         REWIND 2
                   C     CONVERT FROM RASTER TO REAL UNITS
                         IX=(KX-KXD)*40./SF
                         IY=(KY-KYD)*40./SF
                      90 JXL=JX
                         JYL=JY
                   C     SET TOLERANCES
                         ITOL=200./SF
                         TOL=0.4/SF
                         READ (2,100) ICOR,IT,JX,JY
                     100 FORMAT (4A4)
                         ITB=MOD(IT,100)
                   C     IF END OF DATA THEN RETURN
                         IF (ITB.NE.9) GO TO 120
                         BACKSPACE 2
                         RETURN
                   C
                     120 IF (ITB.NE.3.AND.ITB.LT.50) GO TO 150
                         IF (JX.LE.IX-ITOL.OR.JX.GE.IX+ITOL) GO TO 90
                         IF (JY.LE.IY-ITOL.OR.JY.GE.IY+ITOL) GO TO 90
                         GO TO 200
                     150 IF (ITB.EQ.2) GO TO 90
                         IF (IABS(JX-JXL).GE.ITOL.OR.IABS(IX-JX).GE.ITOL) GO TO 1
                         IF (IY.GE.JY.AND.IY.LE.JYL) GO TO 200
                         IF (IY.LE.JY.AND.IY.GE.JYL) GO TO 200
                     180 IF (IABS(JY-JYL).GE.ITOL.OR.IABS(IY-JY).GE.ITOL) GO TO 1
                         IF (IX.GE.JX.AND.IX.LE.JXL) GO TO 200
                         IF (IX.LE.JX.AND.IX.GE.JXL) GO TO 200
                     190 IF (IX.LT.JX.AND.IX.LT.JXL) GO TO 90
                         IF (I/.GT.JX.AND.IX.GT.JXL) GO TO 90
                         IF (IY.LT.JY.AND.IY.LT.JYL) GO TO 90
                         IF (IY.GT.JY.AND.IY.GT.JYL) GO TO 90
                   C
```

```
      TANJ=ABS(FLOAT(JX-JXL)/FLOAT(JY-JYL))
      TANI=ABS(FLOAT(IX-JXL)/FLOAT(IY-JYL))
C
C     CHECK WHETHER THE GRADIENTS ARE THE SAME
      IF (ABS(TANI-TANJ).GE.ABS(TANJ*TOL)) GO TO 90
C
C     IF N=3 THEN DISPLAY HEIGHT AND TYPE OF LINE
  200 IF (N.EQ.3) GO TO 600
      IAT=(IT/100)*100+2
      IF (N.EQ.1) GO TO 300
      BACKSPACE 2
      WRITE (2,100) ICOR,IAT,JX,JY
      KX=FLOAT(JX)*SF/40.
      KY=FLOAT(JY)*SF/40.
C     DISPLAY PLOTTING DOT TO INDICATE THAT THE LINE HAS
C     BEEN DETECTED AND DELETED
      CALL TPLOT(0,KX,KY)
      CALL TPLOT (-1,KX,KY)
      GO TO 650
C
C     DELETE WHOLE MACRO
  300 BACKSPACE 2
      BACKSPACE 2
      READ (2,100) ICT,IT,JX,JY
      IF (IT.EQ.9) GO TO 400
      IF (ICT.EQ.ICOR) GO TO 300
      READ (2,100) ICT,IT,JX,JY
      IF (IT.EQ.9) GO TO 400
      BACKSPACE 2
  350 WRITE (2,100) ICOR,IAT,JX,JY
      KX=JX*(SF/40.)
      KY=JY*(SF/40.)
      CALL TPLOT (0,KX,KY)
      CALL TPLOT (-1,KX,KY)
      READ (2,100) ICT,IT,JX,JY
      IF (IT.EQ.9) GO TO 400
      BACKSPACE 2
      IF (ICT.EQ.ICOR) GO TO 350
  400 GO TO 650
C
C     DISPLAY HEIGHT AND TYPE OF LINE
  600 IA=IT/100
      IB=ITB
      CALL NEW (21)
  650 READ (2,100) ICOR,IAB,IX,IY
      IF (IAB.NE.9) GO TO 650
      BACKSPACE 2
      RETURN
      END
```

```
      SUBROUTINE DPLOT
C
C     THIS SUBROUTINE PLOTS THE MAP ON A STANDARD DRUM
C     PLOTTER.  THE OUTPUT IS FULL-SCALE.
C
C
      COMMON /A/ IX,IY,KX,KY,IA,IB,IC(37),SF,XY(2),ILET(26),
     1NUM(10),P,ICOR,IS(15),THETA,KXD,KYD,IBF
C
      IBL=IB
C     CONVERT JOB NUMBER TO I4 FORMAT
      ENCODE (4,50,MT) IS(8)
   50 FORMAT (I4)
C     SCALE FACTOR TO GIVE TRUE SIZE
      CALL FACTOR (0.0005)
C     WRITE END OF DATA
      IT=9
      WRITE (2,100) IT,IT,IT,IT
      REWIND 2
C
   90 READ (2,100) ICOR,IAB,IX,IY
  100 FORMAT (4A4)
       X=FLOAT(IX)
       Y=FLOAT(IY)
      IB=MOD(IAB,100)
      GO TO (200,170,90,200,200,200,200,200,300),IB
      IB10=IB-9
      GO TO (200,200,200,200),IB10
      IF (IB.GE.50.AND.IB.LE.76) GO TO 260
      GO TO 90
C
C     DRAW LINE
  200 CALL PLOT (X,Y,2)
      GO TO 90
C
C     NO LINE, MOVE ONLY
  170 CALL PLOT (X,Y,3)
      GO TO 90
C
C     PLOT LETTERS
  260 I=IB-49
      CALL SYMBOL (X,Y,250.,ILET(I),0,1)
      GO TO 90
C
C     WRITE DIAGRAM NUMBER
  300 CALL SYMBOL (0.1,0.1,400.,MT,0,4)
      CALL PLOT (0.0,0.0,3)
C
C     WIND ON PAPER
      CALL NUPAGE (4.0)
      BACKSPACE 2
      IB=IBL
      RETURN
      END
```

```
      SUBROUTINE EM(I)
C
C     THIS SUBROUTINE CONVERTS THE BRAILLE CODE INTO THE
C     ACTUAL POSITIONS OF DOTS
C     IS(9)=1     AMERICAN BRAILLE CELL SIZE
C     IS(9)=2     ENGLISH BRAILLE CELL SIZE
C     IS(9)=3     GIANT DOT BRAILLE CELL
C     IS(9)=4     MICRO DOT BRAILLE CELL
C     THETA       ANGLE FROM THE HORIZONTAL FOR BRAILLE TEXT
C
      COMMON /A/ IX,IY,KX,KY,IA,IB,IC(37),SF,XY(2),ILET(26),
     1NUM(10),P,ICOR,IS(15),THETA,KXD,KYD,IBF
C
      IAB=2203
       L=IC(I)
       K1=L/100000
      L=L-K1*100000
       K2=L/10000
      L=L-K2*10000
       K3=L/1000
      L=L-K3*1000
       K4=L/100
      L=L-K4*100
       K5=L/10
      K6=L-K5*10
      SFBRL=1.0
      IF (IS(9).EQ.3) SFBRL=1.25
      IF (IS(9).EQ.4) SFBRL=0.75
      DA=SFBRL*200.
C
      IF (K1.EQ.1) WRITE (2,200) ICOR,IAB,IX,IY
      IX=FLOAT(IX)+DA*SIN(THETA)
      IY=FLOAT(IY)-DA*COS(THETA)
      IF (K2.EQ.1) WRITE (2,200) ICOR,IAB,IX,IY
      IX=FLOAT(IX)+DA*SIN(THETA)
      IY=FLOAT(IY)-DA*COS(THETA)
      IF (K3.EQ.1) WRITE (2,200) ICOR,IAB,IX,IY
      IF (IS(9).EQ.2) GO TO 100
      IX=FLOAT(IX)+DA*COS(THETA)
      IY=FLOAT(IY)+DA*SIN(THETA)
      GO TO 150
  100 IX=FLOAT(IX)+180.*COS(THETA)
      IY=FLOAT(IY)+180.*SIN(THETA)
  150 IF (K6.EQ.1) WRITE (2,200) ICOR,IAB,IX,IY
      IX=FLOAT(IX)-DA*SIN(THETA)
      IY=FLOAT(IY)+DA*COS(THETA)
      IF (K5.EQ.1) WRITE (2,200) ICOR,IAB,IX,IY
      IX=FLOAT(IX)-DA*SIN(THETA)
      IY=FLOAT(IY)+DA*COS(THETA)
      IF (K4.EQ.1) WRITE (2,200) ICOR,IAB,IX,IY
      IX=FLOAT(IX)+DA*1.5*COS(THETA)
      IY=FLOAT(IY)+DA*1.5*SIN(THETA)
  200 FORMAT (4A4)
       RETURN
      END
```

```
      SUBROUTINE FIRST
C
C     THIS SUBROUTINE REGENERATES THE DISPLAY ON THE VDU
C
      COMMON /A/ IX,IY,KX,KY,IA,IB,IC(37),SF,XY(2),ILET(26),
     1NUM(10),P,ICOR,IS(15),THETA,KXD,KYD,IBF
C
      IS(2)=0
      IS(3)=0
      IBL=IB
      REWIND 2
C     ERASES THE SCREEN
      CALL ERASE
      CALL TPLOT (0,0,0)
C
   90 READ (2,100) ICOR,IAB,IX,IY
  100 FORMAT (4A4)
C     CONVERTS REAL TO RASTER UNITS
      KX=IX*(SF/40.)-KXD
      KY=IY*(SF/40.)-KYD
      IB=MOD(IAB,100)
      GO TO (150,200,250,150,150,150,150,150,300),IB
      IB9=IB-9
      GO TO (150,150,150,150),IB9
      IF (IB.GE.50.AND.IB.LE.76) GO TO 270
      GO TO 90
C
C     DRAW LINE
  150 CALL TPLOT (1,KX,KY)
      GO TO 90
C
C     NO LINE, MOVE ONLY
  200 CALL TPLOT (0,KX,KY)
      GO TO 90
C
  250 IF (KX.LT.0.OR.KY.LT.0) GO TO 90
      IF (KX.GE.1023.OR.KY.GE.769) GO TO 90
C     DISPLAY DOT IF ON SCREEN
      CALL TPLOT (0,KX-15,KY)
      CALL ALPHA
      OUTPUT (10) '.'
      GO TO 90
C
C     PLOT LETTERS
  270 CALL TPLOT (0,KX,KY)
      CALL ALPHA
      WRITE (10,280) ILET(IB-49)
  280 FORMAT (A1)
      GO TO 90
C
  300 BACKSPACE 2
      IB=IBL
      RETURN
      END
```

```
      SUBROUTINE GECTAPE
C
C     THE NEXT FIVE SUBROUTINES FORM THE POST-PROCESSOR FOR
C     THE NUMERICALLY-CONTROLLED MACHINE TOOL.  THE PUNCHED
C     PAPER TAPE PRODUCED BY THESE SUBROUTINES IS THE DATA
C     TAPE FOR THE ENGRAVING PROGRAM ON THE GEC 90/2.
C
C
      COMMON /A/ IX,IY,KX,KY,IA,IB,IC(37),SF,XY(2),ILET(26),
     1NUM(10),P,ICOR,IS(15),THETA,KXD,KYD,IBF
      COMMON /X/ IARRAY(6),IAR(6),ARR(6),D1,D2,D3,XL,YL,XT,YT
C
      IAT=IA
      IBL=IB
C     WRITE END OF DATA
      IT=9
      WRITE (2,100) IT,IT,IT,IT
      REWIND 2
      XT=5.0
      YT=5.0
      IAL=0
C
C     STANDARD DATA FOR THE ENGRAVING PROGRAM
      IARRAY(1)=8Z6AD30D6A
      IARRAY(2)=8ZE940F4F0
      IARRAY(3)=8Z40F4F00D
      IARRAY(4)=8Z6AC8404B
      IARRAY(5)=8ZF50D6AC1
      IARRAY(6)=8Z40F1F04B
      CALL GECPT (6,IARRAY)
C
   90 XL=XT
      YL=YT
      READ (2,100) ICOR,IAB,IX,IY
  100 FORMAT (4A4)
      IA=IAB/100
      IB=MOD (IAB,100)
      IF (IB.EQ.9) GO TO 5000
C
      IF (IA.EQ.IAL) GO TO 200
C     PUNCH NEW HEIGHT OF EMBOSSING
      CALL GDEPTH (IA)
      IAL=IA
C
C     CONVERT UNITS TO INCHES
  200 XT=FLOAT(IX)/2000.
      YT=FLOAT (IY)/2000.
C     CHECK THAT INSIDE MAXIMUM DIMENSIONS
      IF (XT.LT.0.0.OR.XT.GT.10.0) GO TO 90
      IF (YT.LT.0.0.OR.YT.GT.10.0) GO TO 90
      D1=0.0
      D2=0.0
      D3=0.0
      GO TO (310,90,330,340,350,360,370,380,5000,400,410,420)
C     IF A LETTER SYMBOL GO TO 1000
```

```
      IF (IB.GE.50.AND.IB.LE.76) GO TO 1000
      OUTPUT(108) IB
      GO TO 90
C
C     ENGRAVE LINE
  310 CALL GLINE (XL,YL,XT,YT)
      GO TO 90
C
C     ENGRAVE DOT (SMALL CIRCLE)
  330 CALL GLINE (XT,YT,XT,YT)
      GO TO 90
C
C     ENGRAVE DOTTED LINE (IB=4)
  340 D1=0.05
      CALL GDOTS
      GO TO 90
C
C     ENGRAVE DOTTED LINE TYPE 5
  350 D1=0.15
      CALL GDOTS
      GO TO 90
C
C     ENGRAVE DOTTED LINE TYPE 6
  360 D1=0.25
      CALL GDOTS
      GO TO 90
C
C     ENGRAVE DASHED LINE TYPE 7
  370 D1=0.2
      D2=0.2
      CALL GDOTS
      GO TO 90
C
C     ENGRAVE DASHED LINE TYPE 8
  380 D1=0.1
      D2=0.1
      CALL GDOTS
      GO TO 90
C
C     ENGRAVE DASHED LINE TYPE 10
  400 D1=0.3
      D2=0.2
      CALL GDOTS
      GO TO 90
C
C     ENGRAVE DOT-DASH LINE TYPE 11
  410 D1=0.1
      D2=0.2
      D3=0.1
      CALL GDOTS
      GO TO 90
C
C     ENGRAVE DOT-DASH LINE TYPE 12
  420 D1=0.2
      D2=0.4
      D3=0.2
```

```
      CALL GDOTS
      GO TO 90
C
C     ENGRAVE LETTER SYMBOL
 1000 CALL GOLET(ILET(IB-49),XT,YT)
      GO TO 90
C
C     ENGRAVE JOB NUMBER AND UP HEAD
 5000 CALL GDEPTH (10)
      IARRAY(1)=8Z6AE940F9
      IARRAY(2)=8Z40F9406A
      IARRAY(3)=8ZC740F040
      IARRAY(4)=8ZF0404040
      IARRAY(5)=8Z400D6AC3
      ENCODE (4,5500,IAR) IS(8)
 5500 FORMAT (I4)
      IARRAY(6)=IAR(1)
      IARRAY(7)=8Z0D6A5CE4
      IARRAY(8)=8Z406AC50D
      CALL GECPT (8,IARRAY)
C
      BACKSPACE 2
      IA=IAT
      IB=IBL
C
      RETURN
      END
```

```
      SUBROUTINE GLINE (X1,Y1,X2,Y2)
C
C     THIS SUBROUTINE CREATES THE DATA TAPE FOR ENGRAVING
C     A LINE FROM (X1,Y1) TO (X2,Y2)
C
C
      COMMON /X/ IARRAY(6),IAR(6),ARR(6),D1,D2,D3,XL,YL,XT,YT
C
C     IF A CONTINUATION LINE THEN USE COMPACT FORMAT
      IF (X1.EQ.XS.AND.Y1.EQ.YS) GO TO 300
      ARR(1)=X1
      ARR(2)=Y1
C
C     IF A LINE OF ZERO LENGTH THEN ENGRAVE SMALL CIRCLE
      IF (X1.EQ.X2.AND.Y1.EQ.Y2) GO TO 450
C
C     ENGRAVE LINE, FULL FORMAT
      ARR(3)=X2
      ARR(4)=Y2
      ENCODE(24,100,IAR)ARR
  100 FORMAT (4F5.2)
      IARRAY(1)=8Z406AC440
      DO 200 I=1,5
  200 IARRAY(I+1)=IAR(I)
      CALL GECPT (6,IARRAY)
      GO TO 500
C
C     ENGRAVE LINE, COMPACT FORMAT
  300 ARR(1)=X2
      ARR(2)=Y2
      ENCODE (12,350,IAR) ARR
  350 FORMAT (2F5.2,2X)
      IARRAY(1)=8Z6AC4405B
      DO 400 I=1,3
  400 IARRAY(I+1)=IAR(I)
      CALL GECPT (4,IARRAY)
      GO TO 500
C
C     ENGRAVE FULL-STOP (SMALL CIRCLE)
  450 ARR(1)=ARR(1)-0.01
      ENCODE (12,350,IAR) ARR
      IARRAY(1)=8Z406AC740
      DO 470 I=1,3
  470 IARRAY(I+1)=IAR(I)
      IARRAY(5)=8Z6AC34805
      CALL GECPT (5,IARRAY)
C
  500 XS=X2
      YS=Y2
C
      RETURN
      END
```

```
      SUBROUTINE GDOTS
C
C     THIS SUBROUTINE ENGRAVES DOTTED, DASHED AND DOT-DASH
C     LINES AT ANY ANGLE.
C
C
      COMMON /A/ IX,IY,KX,KY,IA,IB,IC(37),SF,XY(2),ILET(26),
     1NUM(10),P,ICOR,IS(15),THETA,KXD,KYD,IBF
      COMMON /X/ IARRAY(6),IAR(6),ARR(6),D1,D2,D3,XL,YL,XT,YT
C
      FRACT=ABS((XT-XL)/(YT-YL))
C     SET MAXIMUM VALUE OF THE TANGENT TO BE 500
      IF (FRACT.GT.500.) FRACT=500.
      Y1=D1/SQRT(1.0+FRACT*FRACT)
      X1=FRACT*Y1
      Y2=Y1*D2/D1
      X2=FRACT*Y2
      Y3=Y1*D3/D1
      X3=FRACT*Y3
      DIST=(XT-XL)**2+(YT-YL)**2
C
      IF((YT-YL).GE.0.0) GO TO 20
      Y1=-Y1
      Y2=-Y2
      Y3=-Y3
   20 IF ((XT-XL).GE.0.0) GO TO 30
      X1=-X1
      X2=-X2
      X3=-X3
C
   30 XC=XL
      YC=YL
   90 XB=XC+X1
      YB=YC+Y1
      XC=XB+X2
      YC=YB+Y2
      DOST=(XC-XL)**2+(YC-YL)**2
      IF (DOST.LT.DIST) GO TO 100
      DUST=(XB-XL)**2+(YB-YL)**2
      IF (DUST.GE.DIST) RETURN
      IF (IB.GE.7) CALL GLINE (XB,YB,XT,YT)
      RETURN
C
  100 CALL GLINE (XB,YB,XC,YC)
      IF (IB.LE.10) GO TO 90
      XC=XC+X3
      YC=YC+Y3
      DOST=(XC-XL)**2+(YC-YL)**2
      IF (DOST.GT.DIST) RETURN
      CALL GLINE (XC,YC,XC,YC)
      GO TO 90
C
      END
```

```
      SUBRØUTINE GØLET(LET,X,Y)
C
C     THIS SUBRØUTINE ENGRAVES LETTER SYMBØLS
C
C
      DIMENSIØN ARR(2),IARR(10)
      ARR(1)=X
      ARR(2)=Y
      ENCØDE (12,20,IARR)ARR
   20 FØRMAT (2F5.2)
      DØ 50 I=1,3
   50 IARR(7-I)=IARR(4-I)
      IARR(1)=8Z6AE940F7
      IARR(2)=8Z40F7400D
      IARR(3)=8Z406AC740
      IARR(7)=8Z40406AC3
      IARR(8)=IAND(LET,8ZFF000000)+8Z00050D6A
      IARR(9)=8ZE940F3F0
      IARR(10)=8Z40F3FC0D
      CALL GECPT (10,IARR)
C
      RETURN
      END
```

```
      SUBRØUTINE GDEPTH (IAT)
C
C     THIS SUBRØUTINE SETS A NEW DEPTH FØR THE ENGRAVING
C     MACHINE
C
      CØMMØN /X/ IARRAY(6),IAR(6),ARR(6),D1,D2,D3,XL,YL,XT,YT
C
      IARRAY(1)=IAT
      ENCØDE (4,300,IAR) IARRAY
  300 FØRMAT (I2,2X)
      IAR(2)=IAR(1)
      IAR(1)=8Z406A5CC4
C
C     PUNCH TAPE
      CALL GECPT(2,IAR)
C
      RETURN
      END
```

```
      SUBROUTINE IANEXT (N)
C
C     THIS SUBROUTINE ACCEPTS NUMERICAL DATA KEYED-IN FROM
C     THE VDU KEYBOARD
C
C     N=1         HEIGHT (IA)
C     N=2         LINE TYPE (IB)
C     N=3         DISPLAY SCALE FACTOR (SF)
C     N=4         SYMBOL NUMBER (IS(4))
C     N=5         CO-ORDINATE TABLE SCALE FACTOR (P)
C     N=6         SCALE FACTER
C     N=7         X SCALE FACTOR
C     N=8         Y SCALE FACTOR
C     N=9         BRAILLE CELL SIZE (IS(9))
C     N=10        UNITS, INCHES OR METRIC (IS(10))
C     N=14        JOB NUMBER (IS(8))
C     N=15        SYMBOL SIZE (IS(11))
C     N=16        SYMBOL QUADRANT (IS(12))
C     N=17        LETTER INPUT
C     N=18        SPECIAL FUNCTIONS
C                     1     MANHATTAN
C                     2     SCISSOR
C
C
      COMMON /A/ IX,IY,KX,KY,IA,IB,IC(37),SF,XY(2),ILET(26),
     1NUM(10),P,ICOR,IS(15),THETA,KXD,KYD,IBF
C
      IBD=0
      IDT=4
      ISTAT=0
      IE=9
      IF (N.EQ.17) GO TO 1700
C
C     MOVE DATA FROM BUFFER INTO STORE
      CALL CMOVE (2,ICA,IBD,IDT,ISTAT)
      DECODE (4,150,ICA),IT
  150 FORMAT (I4)
      GO TO (100,200,300,400,500,600,600,600,900,1000),N
      N=N-13
      GO TO (1400,1500,1600,1700,1800),N
      GO TO 5000
C
C     HEIGHT, MAXIMUM VALUE=0.099 INCHES
  100 IA=IT
      IF (IS(10).EQ.2) IA=FLOAT(IA)/25.4
      IF (IA.LT.99) GO TO 5000
      CALL NEW (11)
      IA=99
      GO TO 5000
C
C     LINE TYPE, MAXIMUM VALUE=99
  200 IB=IT
      IF (IB.GT.99) CALL NEW(12)
      GO TO 5000
C
```

```
C      DISPLAY SCALE FACTØR
   300 SF=FLØAT(IT)*0.015
       WRITE (2,350) IE,IE,IE,IE
   350 FØRMAT (4A4)
C      REGENERATE DISPLAY
       CALL FIRST
       GØ TØ 5000
C
C      SYMBØL NUMBER, MAXIMUM VALUE=53
   400 IS(4)=IT
       IF (IS(4).GT.53) CALL NEW (12)
       GØ TØ 5000
C
C      CØ-ØRDINATE TABLE SCALE FACTØR
   500 P=FLØAT(IT)/4.
       GØ TØ 5000
C
C      SCALE FACTØRS
   600 WRITE (2,350) IE,IE,IE,IE
       REWIND 2
   650 READ (2,350) ICØR,IAB,IX,IY
       BACKSPACE 2
       IF (N.EQ.6.ØR.N.EQ.7) IX=(IX*IT)/100
       IF (N.EQ.6.ØR.N.EQ.8) IY=(IY*IT)/100
       WRITE (2,350) ICØR,IAB,IX,IY
       IF (IAB.NE.9) GØ TØ 650
       BACKSPACE 2
       GØ TØ 5000
C
C      BRAILLE CELL SIZE, MAXIMUM VALUE = 4
   900 IS(9)=IT
       IF (IS(9).GT.4) CALL NEW(12)
       GØ TØ 5000
C
C      UNITS, MAXIMUM VALUE = 2
  1000 IS(10)=IT
       IF (IS(10).GT.2) CALL NEW(12)
       GØ TØ 5000
C
C      JØB NUMBER
  1400 IS(8)=IT
       GØ TØ 5000
C
C      SYMBØL SIZE
  1500 IS(11)=IT
       GØ TØ 5000
C
C      SYMBØL QUADRANT, MAXIMUM VALUE = 8
  1600 IS(12)=IT
       IF (IT.GT.8) CALL NEW(12)
       GØ TØ 5000
C
C      LETTER INPUT, SINGLE CHARACTER
  1700 ICA=8Z00000000
       ICA=8Z00000000
       CALL CMØVE (2,ICA,IBC,1,ISTAT)
```

```
      ICA=ISL(ICA,-24)
      DO 1750 I=1,26
      LT=ISL(ILET(I),-24)
 1750 IF (ICA.EQ.LT) GO TO 1780
      GO TO 5000
 1780 IB=I+49
      GO TO 5000
C
C     SPECIAL FUNCTIONS
 1800 IF (IT.EQ.1) CALL MANHATTAN
      IF (IT.EQ.2) CALL SCISSOR
      IF (IT.NE.3) GO TO 1850
C     LIST DATA ON LINE PRINTER
      WRITE (2,350) IE,IE,IE,IE
      REWIND 2
 1820 READ (2,350) ICOR,IAB,IX,IY
      WRITE (108,1830) ICOR,IAB,IX,IY
 1830 FORMAT (4(5X,I5))
      IF (IAB.NE.9) GO TO 1820
      BACKSPACE 2
      GO TO 5000
 1850 CONTINUE
      GO TO 5000
C
C     DISPLAY CROSSWIRES
 5000 CALL JOYSTIK (2Z65)
C
      END
```

```
      SUBROUTINE INNER
C
C     THIS SUBROUTINE TRANSFERS TEXT FROM THE BUFFER INTO STO
C
C
      COMMON /A/ IX,IY,KX,KY,IA,IB,IC(37),SF,XY(2),ILET(26),
     1NUM(10),P,ICOR,IS(15),THETA,KXD,KYD,IBF
       DIMENSION ICHAR(81)
C
      DO 105 I=1,81
  105 ICHAR(I)=8Z40404040
C
      ISTAT=0
      IBD=0
      CALL CMOVE (2,ICHAR,IBD,IS(7),ISTAT)
      IS(1)=0
      ID=IS(7)/4+1
       DO 200 I=1,ID
  200 CALL LETTER (ICHAR(I))
C
      ICOR=ICOR+1
C     DISPLAY CROSSWIRES
      CALL JOYSTIK(2Z65)
      END
```

```
      SUBROUTINE JOYCON
C
C     THIS SUBROUTINE READS THE (X,Y) CO-ORDINATES OF THE
C     CROSSWIRES AND CONVERTS FROM RASTER TO REAL UNITS.
C     THE CHARACTER INPUT FROM THE KEYBOARD THEN DETERMINES
C     THE ACTION TO BE TAKEN.
C
C
      COMMON /A/ IX,IY,KX,KY,IA,IB,IC(37),SF,XY(2),ILET(26),
     1NUM(10),P,ICOR,IS(15),THETA,KXD,KYD,IOF
      DIMENSION JPUN (10)
      DATA JPUN/';','-',',','.',':','/','@',' ',' ',' '/
C
C     SET-UP DEFAULT VALUES
      ISP=8Z00000000
      ISTAT=0
      IDT=4
      IT=9
C
C     MOVE JOYSTICK INFORMATION FROM THE BUFFER INTO STORE
      CALL JOYXY (IL,IX,IY)
C
C     ADJUST FOR RELATIVE DISPLAY ORIGIN
      KX=IX
      KY=IY
C
C     CONVERT TO REAL UNITS
      IX=(IX+KXD)*40./SF
      IY=(IY+KYD)*40./SF
C
C
       DO 120 I=1,26
      LT=ISL(ILET(I),-24)
  120 IF (IL.EQ.LT) GO TO 130
      DO 125 I=1,10
      LT=ISL(NUM(I),-24)
      JT=ISL(JPUN(I),-24)
      IF (IL.EQ.JT) GO TO 150
  125 IF (IL.EQ.LT) GO TO 135
       GO TO 1000
C
  130 GO TO (210,220,230,240,250,260,270,280,290,300),I
      I=I-10
      GO TO (310,320,330,340,350,360,370,380,390,400),I
      I=I-10
      GO TO (410,420,430,440,450,460),I
  135 GO TO (500,510,520,530,540,550,560,570,580,590),I
  150 GO TO (263,600,610,620,630,640,650,230,230,230),I
C
C
C      A   HEIGHT OF EMBOSSING
  210 CALL NEW(1)
      GO TO 1400
C
C      B   BRAILLE
```

```
  220 SFBRL=1.0
      ICOR=ICOR+1
C     SETS BRAILLE CELL SIZE
      IF (IS(9).EQ.3) SFBRL=1.25
      IF (IS(9).EQ.4) SFBRL=0.75
      IX=IX-400.*SFBRL*SIN(THETA)
      IY=IY+400.*SFBRL*COS(THETA)
      CALL ALPHA
      IS(7)=80
      KYT=KY-20.*SF*SFBRL
C     PUT PLOTTING AT THE BEGINNING OF THE NEXT LINE
      CALL TPLOT (0,KX,KYT)
      CALL TPLOT (-1,KX,KYT)
      CALL TPLOT (0,KX,KY)
      CALL ALPHA
C     READ IN UP TO 80 CHARACTERS
      CALL CREAD (2,IS(7),ISTAT,2Z64)
      GO TO 1500
C
C     C   MENU, DISPLAY LIST OF COMMANDS ON RH SIDE OF SCREEN
  230 CALL LIST
      GO TO 1000
C
C     D   DELETE WHOLE MACROS
  240 CALL DELETE (1)
      GO TO 1000
C
C     E   END, RELEASE PROGRAM FROM FOREGROUND
  250 WRITE (2,265) IT,IT,IT,IT
      REWIND 2
      CALL CSTOP(2)
      CALL RLSOV
      GO TO 1000
C
C     F   MOVE, ONLY ELEMENTS AND NOT COMPLETE MACROS
  260 CALL VMOVE (1)
      GO TO 1000
C
C     ;   FIRST POINT OF A LINE, LINE TYPE 2
  263 IAB=IA*100+2
      WRITE (2,265) ICOR,IAB,IX,IY
  265 FORMAT (4A4)
      LASTX=KX-KXD
      LASTY=KY-KYD
      CALL ALPHA
C     DRAW PLOTTING DOT
      CALL TPLOT (0,KX,KY)
      CALL TPLOT (-1,KX,KY)
      IF (IS(14).NE.2) ICOR=ICOR+1
      GO TO 1000
C
C     G   GEC TAPE, GENERATE PUNCHED PAPER TAPE FOR DATA TO
C     THE ENGRAVING PROGRAM ON THE GEC 90/2 COMPUTER
C     PUNCH BLANK LEADER TAPE (4 INCHES)
  270 DO 275 I=1,10
  275 WRITE (128,265) ISP,ISP,ISP,ISP
```

```
      CALL GEOTAPE
      DO 278 I=1,10
  278 WRITE (128,265) ISP,ISP,ISP,ISP
      GO TO 1000
C
C     H   P/T INPUT, READS DATA FROM PAPER TAPE
  280 REWIND 2
      ISS=2
C     READ SYMBOL NUMBER,JOB NUMBER AND BRAILLE CELL SIZE
      READ (125,368) IS(4),ISS,IS(8),IS(9)
  285 READ (125,368) ICOR,IAB,IX,IY
      WRITE (2,265) ICOR,IAB,IX,IY
      IF (IAB.NE.9) GO TO 285
C     REGENERATE DISPLAY
       CALL FIRST
      GO TO 1000
C
C     I   REGENERATE DISPLAY
  290 WRITE (2,265) IT,IT,IT,IT
      CALL FIRST
      GO TO 1000
C
C     J   D. BOARD, INPUT OF DATA FROM CO-ORDINATE TABLE
  300 CONTINUE
      IBF=IB
      IF (IS(6).EQ.0) CALL NEW(13)
C     DISABLE VDU INTERRUPTS
      CALL DISAB (2Z64,2Z65,2Z6A)
C     ENABLE CO-ORDINATE TABLE INTERRUPTS
      CALL ENAB (2Z66,2Z67,2Z68)
      GO TO 1500
C
C     K   TYPE IB, INPUT NEW LINE TYPE
  310 CALL NEW(2)
      GO TO 1400
C
C     L   LINE, DRAW LINE FROM PRESENT POSITION
  320 IAB=IA*100+IB
C     IF MACRO DO NOT INCREMENT CORRELATION VALUE
      IF (IS(14).NE.2) ICOR=ICOR+1
      WRITE (2,265) ICOR,IAB,IX,IY
      IF (IS(14).NE.2) ICOR=ICOR+1
      CALL TPLOT (0,LASTX,LASTY)
      IF (IB.EQ.3) CALL ALPHA
      IF (IB.GE.50.AND.IB.LE.76) GO TO 325
C     DRAW LINE
      CALL TPLOT (1,KX,KY)
      LASTX=KX-KXD
      LASTY=KY-KYD
      GO TO 1000
  325 CALL TPLOT (0,KX,KY)
      I=IB-49
      CALL ALPHA
C     DRAW LETTER
      CALL CWRITE (2,ILET(I),0,1,ISTAT)
      GO TO 1000
```

```
C
C     M   MOVE, COMPLETE MACRO
  330 CALL VMOVE (2)
      GO TO 1000
C
C     N   NEXT, SCRATCH DATA FILE AND ERASE SCREEN
  340 IF (IS(13).EQ.2) GO TO 345
      IS(13)=2
      GO TO 1100
C
  345 IS(13)=1
      REWIND 2
      J1=0
      J2=2
      ICOR=10
      WRITE (2,265) J1,J2,J1,J1
      WRITE (2,265) IT,IT,IT ,IT
C     REGENERATE DISPLAY
      CALL FIRST
C     INCREMENT JOB NUMBER
      IS(8)=IS(8)+1
      GO TO 1000
C
C     O   SCALE, CHANGE DISPLAY SCALE FACTOR
  350 CALL NEW(3)
      GO TO 1400
C
C     P   P/T DUMP, PUNCH DATA ON PAPER TAPE
  360 WRITE (2,265) IT,IT,IT,IT
      REWIND 2
      DO 362 I=1,10
C     PUNCH BLANK LEADER TAPE (4 INCHES)
  362 WRITE (128,265) ISP,ISP,ISP,ISP
      ISS=2
C     PUNCH SYMBOL NUMBER,JOB NUMBER AND BRAILLE CELL SIZE
      WRITE (128,368) IS(4),ISS,IS(8),IS(9)
C     PUNCH DATA IN COMPACT FORMAT (SQUEEZE ON DATA FILE)
      READ (2,265) ICORA,IABA,IXA,IYA
  363 IBT1=MOD(IABA,100)
      READ (2,265) ICORB,IABB,IXB,IYB
      IBT2=MOD(IABB,100)
      IF (IBT1.EQ.2.AND.IBT2.EQ.2) GO TO 364
      WRITE (128,368) ICORA,IABA,IXA,IYA
      IF (IBT2.EQ.9) GO TO 366
  364 ICORA=ICORB
      IABA=IABB
      IXA=IXB
      IYA=IYB
      GO TO 363
  366 WRITE (128,368) IT,IT,IT,IT
  368 FORMAT (4I5)
      BACKSPACE 2
      DO 369 I=1,10
  369 WRITE (128,265) ISP,ISP,ISP,ISP
      GO TO 1000
C
```

```
C     Q   PLOT, OUTPUT ON DIGITAL PLOTTER
  370 CALL DPLOT
      GO TO 1000
C
C     R   D. SCALE, CHANGE SCALE FACTOR FROM CO-ORDINATE
C     TABLE (P)
  380 CALL NEW(5)
      GO TO 1400
C
C     S   SYM TYPE, CHANGE SYMBOL NUMBER
  390 CALL NEW(4)
      GO TO 1400
C
C     T   SYM POS, POSITION STANDARD SYMBOL ON THE SCREEN
  400 CALL SYMB
      GO TO 1000
C
C     U   RESET, RESETS DEFAULT VALUES AND REGENERATES DISPLA
  410 SF=1.5
      THETA=0.0
      KXD=0
      KYD=0
      IS(6)=0
      WRITE (2,265) IT,IT,IT,IT
      CALL FIRST
C     DISPLAY CURRENT VALUES AT THE TOP OF THE SCREEN
      CALL NEW(20)
      GO TO 1000
C
C     V   GRID, DRAWS A 1 INCH GRID ON THE SCREEN
  420 INCR=50.*SF
  421 JY=0
      JX=0
      DO 422 J=1,11
      CALL TPLOT (0,JX-KXD,-KYD)
      CALL TPLOT (1,JX-KXD,10*INCR-KYD)
      JX=JX+INCR
      CALL TPLOT (0,-KXD,JY-KYD)
      CALL TPLOT (1,10*INCR-KXD,JY-KYD)
  422 JY=JY+INCR
      GO TO 1000
C
C     W   SIZE, CHANGES THE REAL SIZE OF THE MAP
  430 CALL NEW(6)
      GO TO 1400
C
C     X   X SIZE, CHANGES THE REAL SIZE IN THE X AXIS
  440 CALL NEW(7)
      GO TO 1400
C
C     Y   Y SIZE, CHANGES THE REAL SIZE IN THE Y AXIS
  450 CALL NEW(8)
      GO TO 1400
C
C     Z   SPECIAL FUNCTIONS
  460 CALL NEW(18)
```

```
      GO TO 1400
C
C     1   BRL TYPE, DETERMINES THE SIZE OF THE BRAILLE CELL
  500 CALL NEW(9)
      GO TO 1400
C
C     2   UNITS, INCHES OR METRIC
  510 CALL NEW(10)
      GO TO 1400
C
C     3   CM GRID, DRAWS A 1 CM GRID ON THE SCREEN
  520 INCR=50.*SF/2.54
      GO TO 421
C
C     4   CHECKOUT, OUTPUTS THE CURRENT VALUES AT TOP OF SCRE
  530 CALL NEW(20)
      GO TO 1000
C
C     5   QK DEL, DELETES SINGLE ELEMENTS BUT NOT WHOLE MACRO
C     THE DISPLAY IS NOT REGENERATED
  540 CALL DELETE (2)
      GO TO 1000
C
C     6   JOB NUMBER, MAXIMUM VALUE = 9999
  550 CALL NEW(14)
      GO TO 1400
C
C     7   LETTERS, SETS UP SINGLE LETTER POINT SYMBOLS
  560 CALL NEW(17)
      CALL CREAD (2,1,ISTAT,2Z6A)
      GO TO 1500
C
C     8   SYMBOL SIZE
  570 CALL NEW(15)
      GO TO 1400
C
C     9   SYMBOL QUADRANT
  580 CALL NEW(16)
      GO TO 1400
C
C     0   MACRO START, BEGINNING OF GROUP DEFINITION
  590 IS(14)=2
      GO TO 1000
C
C     -   MACRO END, END OF GROUP DEFINITION
  600 IS (14)=1
      ICOR=ICOR+1
      GO TO 1000
C
C     ,   ORIGIN, CHANGES ABSOLUTE ORIGIN
  610 IF (IS(3).EQ.2) GO TO 615
C     OLD ORIGIN
      IS(3)=2
      IXT=IX
      IYT=IY
      CALL TPLOT (0,KX,KY)
```

```
      CALL TPLOT (-1,KX,KY)
      GO TO 1000
C
C     NEW ORIGIN
  615 IS(3)=0
      IXT=IX-IXT
      IYT=IY-IYT
      WRITE (2,265) IT,IT,IT,IT
      REWIND 2
  617 READ (2,265) ICOR,IAB,IX,IY
      BACKSPACE 2
      IX=IX-IXT
      IY=IY-IYT
      WRITE (2,265) ICOR,IAB,IX,IY
      IF (IAB.NE.9) GO TO 617
C     REGENERATE DISPLAY
      CALL FIRST
      GO TO 1000
C
C     .   ANGLE FROM THE HORIZONTAL FOR BRAILLE TEXT
  620 IF (IS(3).EQ.3) GO TO 625
C     FIRST POINT
      IS(3)=3
      IXT=IX
      IYT=IY
      CALL TPLOT (0,KX,KY)
      CALL TPLOT (-1,KX,KY)
      GO TO 1000
C
C     SECOND POINT
  625 IS(3)=0
      THETA=ATAN(FLOAT(IY-IYT)/FLOAT(IX-IXT))
      GO TO 1000
C
C     :   DISPLAY ORIGIN
  630 IF (IS(3).EQ.4) GO TO 635
C     FIRST POINT
      IS(3)=4
      KX1=KX
      KY1=KY
      CALL TPLOT (0,KX,KY)
      CALL TPLOT (-1,KX,KY)
      GO TO 1000
C
C     SECOND POINT
  635 IS(3)=0
      KXD=KX-KX1+KXD
      KYD=KY-KY1+KYD
      WRITE (2,265) IT,IT,IT,IT
C     REGENERATE DISPLAY
      CALL FIRST
      GO TO 1000
C
C     /   DISPLAY HEIGHT AND TYPE OF LINE
  640 IAL=IA
      IBL=IB
```

```
      CALL DELETE (3)
      IA=IAL
      IB=IBL
      GØ TØ 1000
C
C     DØT GRID
  650 INCR=5.*SF
      JX=KX
      JY=KY
      DØ 655 I=1,5
      DØ 652 J=1,5
      CALL TPLØT (0,JX-KXD,JY-KYD)
      CALL TPLØT (-1,JX-KXD,JY-KYD)
  652 JX=JX+INCR
      JX=KX
  655 JY=JY+INCR
      GØ TØ 1000
C
C     DISPLAY CRØSSWIRES
 1000 IS(13)=1
 1100 CALL JØYSTIK (2Z65)
      RETURN
C
C     READ FØUR CHARACTERS
 1400 CALL CREAD (2,IDT,ISTAT,2Z6A)
 1500 CØNTINUE
C
      END
```

```
      SUBROUTINE LETTER (ICHAR)
C
C     THIS SUBROUTINE CONVERTS TEXT TO GRADE 1 BRAILLE
C
C
      COMMON /A/ IX,IY,KX,KY,IA,IB,IC(37),SF,XY(2),ILET(26),
     1NUM(10),P,ICOR,IS(15),THETA,KXD,KYD,IBF
C
      DIMENSION IAN(8),JPUNCT(10)
       DATA JPUNCT/'.',':',';',',','|','(',')','-','¬','!'/
      DATA JSPACE /' '/
C
      DO 100 I=1,8
  100 IAN(I)=8Z40404040
C
C     PUT 1 CHARACTER PER WORD AND FOLLOW WITH 3 SPACES
      DECODE (16,120,ICHAR) IAN
  120 FORMAT (4A1)
C
       DO 450 J=1,4
      IF (IAN(J).EQ.JSPACE) GO TO 380
C
C     CHECK IF A LETTER
       DO 300 I=1,26
  300 IF (IAN(J).EQ.ILET(I)) GO TO 400
C
C     CHECK IF A NUMERAL
      DO 310 I=1,10
  310 IF (IAN(J).EQ.NUM(I)) GO TO 390
C
C     CHECK IF A PUNCTUATION SIGN
       DO 320 K=1,10
       IF (IAN(J).NE.JPUNCT(K)) GO TO 320
       I=K+27
       GO TO 400
C
  320 CONTINUE
  380 CALL EM (37)
      GO TO 450
C
C     IF PREVIOUS CHARACTER WAS A NUMERAL DO NOT REPEAT THE
C     NUMERAL SIGN
  390 IF (IS(1).EQ.1) GO TO 410
      IS(1)=1
      CALL EM(27)
      GO TO 410
C
  400 IS(1)=0
      IF (I.GT.26) IS(1)=1
  410 CALL EM(I)
  450 CONTINUE
C
      RETURN
      END
```

```
      SUBROUTINE LINE (JX,JY)
C
C     DRAWS LINE FROM CURRENT POSITION TO (JX,JY)
C
C
      COMMON /A/ IX,IY,KX,KY,IA,IB,IC(37),SF,XY(2),ILET(26),
     1NUM(10),P,ICOR,IS(15),THETA,KXD,KYD,IBF
C
      IAB=IA*100+IB
      WRITE (2,200) ICOR,IAB,JX,JY
  200 FORMAT (4A4)
C
C     PLOT ON VDU
      KX=JX*(SF/40.)-KXD
      KY=JY*(SF/40.)-KYD
      IF (IB.EQ.3) GO TO 300
      IF (IB.GE.50.AND.IB.LE.76) GO TO 400
      IF (IB.EQ.2) CALL TPLOT (0,KX,KY)
      IF (IB.NE.2) CALL TPLOT (1,KX,KY)
      RETURN
C
C     DRAW A FULL-STOP
  300 CALL TPLOT (0,KX-15,KY)
      CALL ALPHA
      OUTPUT (10) '.'
      RETURN
C
C     PLOT LETTER
  400 CALL TPLOT (0,KX,KY)
      WRITE (10,450) ILET(IB-49)
  450 FORMAT (A1)
C
      RETURN
      END
```

```
      SUBROUTINE LIST
C
C     THIS SUBROUTINE DISPLAYS THE LIST OF COMMANDS ON THE
C     RH SIDE OF THE SCREEN
C
C
      DIMENSION MES(3,39),MIS(3,4)
      DATA MES/'A   HEIGHT  ','B   BRAILLE ','C   MENU    ',
     1'D   DELETE  ','E   END     ','F   MOVE    ','G   GEC TAPE',
     2'H   PT INPUT','I   RE-DRAW ','J   D.BOARD ','K   TYPE IB ',
     3'L   LINE    ','M   MOVE MAC','N   NEXT    ','O   SCALE   ',
     4'P   PT DUMP ','Q   PLOT    ','R   D.SCALE ','S   SYM TYPE',
     5'T   SYM POS ','U   RESET   ','V   GRID    ','W   SIZE    ',
     6'X   X SIZE  ','Y   Y SIZE  ','Z   FUNCTION','1   BRL TYPE',
     7'2   UNITS   ','3   CM GRID ','4   CHECKOUT','5   QK DEL  ',
     8'6   D NUMBER','7   LETTERS ','8   SYM SIZE','9   QUADRANT',
     9'0   MACRO ST','-   MACRO EN',',   ORIGIN  ','.   ANGLE   '/
      DATA MIS/';   NO LINE ',':   DIS ORIG','/   CHK LINE',
     1'@   DOT GRID'/
C
      DO 100 I=1,39
      CALL TPLOT(0,850,750-I*17)
      CALL ALPHA
  100 WRITE (10,150) (MES(J,I),J=1,3)
  150 FORMAT (1X,3A4)
      DO 200 I=1,4
      CALL TPLOT (0,850,87-I*17)
      CALL ALPHA
  200 WRITE (10,150) (MIS(J,I),J=1,3)
C
      RETURN
      END
```

```
      SUBROUTINE MANHATTAN
C
C     THIS SUBROUTINE MAKES LINES WHICH ARE NEARLY VERTICAL
C     OR HORIZONTAL SO THAT THEY ARE ALONG THE AXES.  MACROS
C     ARE TREATED AS A SINGLE UNIT AND ARE MOVED COMPLETE.
C
C
      ITOL=10
      IX=0
      IY=0
      ICOR=0
C     WRITE END OF DATA
      IT=9
      WRITE (2,50) IT,IT,IT,IT
   50 FORMAT (4A4)
      REWIND 2
C
   90 IXL=IX
      IYL=IY
      ICORL=ICOR
      READ (2,50) ICOR,IAB,IX,IY
      IF (IAB.EQ.9) GO TO 1000
      IF (ICOR.EQ.ICORL) GO TO 250
      IDIFX=0
      IDIFY=0
      IF (IABS(IX-IXL)*ITOL.GT.IABS(IY-IYL)) GO TO 200
      IF (IABS(IX-IXL).GT.300) GO TO 200
      IDIFX=IX-IXL
      IX=IXL
      GO TO 300
C
  200 IF (IABS(IY-IYL)*ITOL.GT.IABS(IX-IXL)) GO TO 90
      IF (IABS(IY-IYL).GT.300) GO TO 90
      IDIFY=IY-IYL
      IY=IYL
      GO TO 300
C
  250 IX=IX-IDIFX
      IY=IY-IDIFY
  300 BACKSPACE 2
      WRITE (2,50) ICOR,IAB,IX,IY
      GO TO 90
C
C     REGENERATE DISPLAY
 1000 CALL FIRST
C
      RETURN
      END
```

```
      SUBROUTINE NEW(K)
C
C     THIS SUBROUTINE WRITES MESSAGES IN THE TOP LEFT-HAND
C     CORNER OF THE SCREEN
C
C
      COMMON /A/ IX,IY,KX,KY,IA,IB,IC(37),SF,XY(2),ILET(26),
     1NUM(10),P,ICOR,IS(15),THETA,KXD,KYD,IBF
C
      DIMENSION MESB(2,4),MESS(4),MES(4,18)
      DATA MES/'HEIGHT OF LINE =','TYPE OF LINE =   ','SCALE
     1'SYMBOL NUMBER = ','C.BOARD SCALE = ','SIZE OF DIAGRAM
     2'X SCALE FACTOR =','Y SCALE FACTOR =','TYPE OF BRAILLE
     3'INCHES OR METRIC','DEPTH TOO LARGE ','VALUE TOO LARGE
     4'CALIBRATE TABLE ','JOB NUMBER =    ','SYMBOL SIZE =
     5'SYMBOL QUADRANT ','SYMBOL LETTER = ','SPECIAL FUNCTIO
      DATA MESB/'AMERICAN','ENGLISH ','GIANTDOT','MICRODOT'/
C
      IS(5)=K
C     SET CURSOR TO TLHC
      CALL HOME
      CALL ALPHA
      ISTAT=0
      IF (IS(2).EQ.0) GO TO 30
      ITOT=IS(2)
C
C     GIVE RIGHT NUMBER OF LINE FEEDS SO THAT DO NOT
C     OVER-WRITE PREVIOUS MESSAGE
      DO 20 I=1,ITOT
   20 CALL CWRITE (2,2Z15,3,1,ISTAT)
C
   30 IS(2)=IS(2)+1
      IF (K.EQ.20.OR.K.EQ.21) GO TO 100
C     WRITE MESSAGE
      WRITE (10,50) (MES(I,K),I=1,4)
   50 FORMAT (4A4)
      RETURN
C
  100 IF (IS(10).EQ.2) GO TO 150
C
C     OUTPUT HEIGHT AND TYPE OF LINE, INCHES
      WRITE (10,120) IA,IB
  120 FORMAT ('HEIGHT OF LINE =',I4,'  THOU',4X,'TYPE OF LIN
      GO TO 200
C
  150 IAT=IFIX(FLOAT(IA)*25.4)
C
C     OUTPUT HEIGHT AND TYPE OF LINE, METRIC
      WRITE (10,170)IAT,IB
  170 FORMAT ('HEIGHT OF LINE =',I4,' MICRONS',2X,'TYPE OF L
  200 IF (K.EQ.21) RETURN
C     CARRIAGE RETURN
      CALL CWRITE (2,2Z15,3,1,ISTAT)
C
C     OUTPUT SYMBOL NUMBER AND BRAILLE CELL SIZE
```

```
      WRITE (10,220) IS(4),MESB(1,IS(9)),MESB(2,IS(9))
  220 FORMAT ('SYMBOL NUMBER ='I4,4X,'TYPE OF BRAILLE =',2A4)
      IPT=P*4.
      CALL CWRITE (2,2Z15,3,1,ISTAT)
C
C     OUTPUT CO-ORDINATE TABLE SCALE FACTOR AND SYMBOL SIZE
      WRITE (10,250) IPT,IS(11)
  250 FORMAT ('D. BOARD SCALE =',I4,4X,'SYMBOL SIZE =',I4)
      CALL CWRITE (2,2Z15,3,1,ISTAT)
C
C     OUTPUT SYMBOL QUADRANT AND JOB NUMBER
      WRITE (10,300) IS(12),IS(8)
  300 FORMAT ('QUADRANT =',I4,10X,'JOB NUMBER =',I4)
      IS(2)=IS(2)+3
C
      RETURN
      END
```

```
      SUBROUTINE SCISSOR
C
C     THIS SUBROUTINE DELETES ALL LINES AND DOTS WHICH ARE
C     OUTSIDE THE RANGE OF THE ENGRAVING MACHINE (10 INS SQ)
C
C
C     WRITE END OF DATA
      IT=9
      WRITE (2,100) IT,IT,IT,IT
  100 FORMAT (4A4)
      REWIND 2
      IX=0
      IY=0
C
  200 IXL=IX
      IYL=IY
      READ (2,100) ICOR,IAB,IX,IY
      IF (IAB.EQ.9) GO TO 400
C
C     IF CURRENT VALUE INSIDE RANGE GO TO 200
      IF(IX.GE.0.AND.IX.LT.20000.AND.IY.GE.0.AND.IY.LT.20000)
     1GO TO 200
C
C     IF LAST VALUE INSIDE RANGE GO TO 200
      IF(IXL.GE.0.AND.IXL.LT.20000.AND.IYL.GE.0.AND.IYL.LT.200
     2 GO TO 200
C
C     WRITE NO LINE, MOVE ONLY
      IAB=(IAB/100)*100+2
      BACKSPACE 2
      WRITE (2,100) ICOR,IAB,IX,IY
      GO TO 200
C
C     REGENERATE DISPLAY
  400 CALL FIRST
C
      RETURN
      END
```

```
      SUBROUTINE SYMB
C
C     THIS SUBROUTINE READS THE SYMBOL DATA FROM DISC AND
C     POSITIONS THE SYMBOL ON THE SCREEN.  THE DATA IS
C     STORED IN A PERMANENT FILE IN AREA D1.
C
C
      COMMON /A/ IX,IY,KX,KY,IA,IB,IC(37),SF,XY(2),ILET(26),
     1NUM(10),P,ICOR,IS(15),THETA,KXD,KYD,IBF
C
      IBL=IB
      IST=IS(4)-1
      REWIND 5
      IF (IST.EQ.0) GO TO 200
C
      DO 200 I=1,IST
   50 READ (5,100) JAB,JX,JY
  100 FORMAT (3A4)
      IF (JAB.EQ.99) RETURN
      IF (JAB.NE.9) GO TO 50
  200 CONTINUE
C
C     NO LINE, MOVE ONLY
      IB=2
      CALL LINE (IX,IY)
C
  300 READ (5,100) IB,JX,JY
      IF (IB.EQ.9) GO TO 400
      JX=FLOAT(JX*IS(11))/100.
      JY=FLOAT (JY*IS(11))/100.
      IF (IS(12).EQ.2.OR.IS(12).EQ.3) JX=-JX
      IF (IS(12).EQ.3.OR.IS(12).EQ.4) JY=-JY
      IF (IS(12).LT.5) GO TO 350
      JXT=JX
      JX=JY
      JY=JXT
      IF (IS(12).EQ.6.OR.IS(12).EQ.7) JX=-JX
      IF (IS(12).EQ.7.OR.IS(12).EQ.8) JY=-JY
C     PLOT LINE
  350 CALL LINE (JX+IX,JY+IY)
      GO TO 300
C
  400 IB=IBL
      ICOR=ICOR+1
C
      RETURN
      END
```

```
      SUBROUTINE VMOVE (N)
C
C     THIS SUBROUTINE MOVES AN END POINT OF A LINE OR A
C     COMPLETE MACRO
C
C
      COMMON /A/ IX,IY,KX,KY,IA,IB,IC(37),SF,XY(2),ILET(26),
     1NUM(10),P,ICOR,IS(15),THETA,KXD,KYD,IBF
C
C     WRITE END OF DATA
      IT=9
      WRITE (2,50) IT,IT,IT,IT
   50 FORMAT (4A4)
      REWIND 2
C
C     CONVERT TO REAL UNITS
      IX=IFIX(FLOAT(KX)*40./SF)
      IY=IFIX(FLOAT(KY)*40./SF)
      IF (IS(3).EQ.1) GO TO 300
      ICT=0
      ITOL=100./SF
C
   90 READ (2,50) ICOR,IAB,JX,JY
      IF (IAB.EQ.9) GO TO 200
      ICT=ICT+1
      IXT=JX+ITOL
      IXB=JX-ITOL
      IYT=JY+ITOL
      IYB=JY-ITOL
      IF (IY.LE.IYB.OR.IY.GE.IYT) GO TO 90
      IF (IX.LE.IXB.OR.IX.GE.IXT) GO TO 90
      KX=IFIX(FLOAT(JX)*SF/40.)-KXD
      KY=IFIX(FLOAT(JY)*SF/40.)-KYD
C
C     DISPLAY PLOTTING DOT TO INDICATE THAT THE POINT HAS
C     BEEN DETECTED
      CALL ALPHA
      CALL TPLOT (0,KX,KY)
      CALL TPLOT(-1,KX,KY)
      ITOT=ICT
      IS(3)=1
      GO TO 90
C
  200 BACKSPACE 2
      RETURN
C
C     MOVE TO NEW POSITION
  300 DO 350 I=1,ITOT
      READ (2,50) ICOR,IAB,JX,JY
  350 IF (IAB.EQ.9) GO TO 400
  360 BACKSPACE 2
      IF (ITOT.EQ.1) GO TO 370
      IAB=JAB
      BACKSPACE 2
      READ (2,50) ICORT,JAB,JXT,JYT
```

```
      IF (ICORT.EQ.ICOR.AND.N.EQ.2) GO TO 360
      READ (2,50) ICORT,IAB,JXT,JYT
      BACKSPACE 2
  370 IXT=IX+JXT-JX
      IYT=IY+JYT-JY
      WRITE (2,50) ICOR,IAB,IXT,IYT
      READ (2,50) ICORT,IAB,JXT,JYT
      BACKSPACE 2
      IF (IAB.EQ.9) GO TO 400
      IF (ICORT.EQ.ICOR.AND.N.EQ.2) GO TO 370
  400 IS(3)=0
  500 READ (2,50) ICOR,IAB,IX,IY
      IF (IAB.NE.9) GO TO 500
      BACKSPACE 2
C
      RETURN
      END
```

```
      SUBROUTINE COORDS
C
C     THIS SUBROUTINE CONVERTS THE VOLTAGES FROM THE
C     CO-ORDINATE TABLE TO (X,Y) VALUES.  IT ALSO ALLOWS
C     FOR THE CALIBRATION OF THE TABLE.
C
C
      COMMON /A/ IX,IY,KX,KY,IA,IB,IC(37),SF,XY(2),ILET(26),
     1NUM(10),P,ICOR,IS(15),THETA,KXD,KYD,IBF
C
      ISTAT=0
      GO TO (200,550,800),IS(6)
      GO TO 2000
C
C     FIRST CALIBRATION POINT, TOP LEFT-HAND CORNER
  200 XTLHC=XY(1)
      YTLHC=XY(2)
      OUTPUT (10)'NOW TOP RIGHT HAND CORNER'
       RETURN
C
C     SECOND CALIBRATION POINT, TOP RIGHT-HAND CORNER
  550 YTRHC=XY(2)
      XTRHC=XY(1)
      V1=XTRHC-XTLHC
      V2=YTLHC-YTRHC
      OUTPUT (10) 'NOW ORIGIN'
       RETURN
C
C     MAKE A AND B POSITIVE NUMBERS
  800 A=P*(XY(1)-XTLHC)/V1
      B=P*(XY(2)-YTRHC)/V2
C
C     THIRD CALIBRATION POINT, ORIGIN
  900 XORG=FX(A,B,P)
      Q=SQRT((A+XORG)*(A-XORG))
      OUTPUT (10) 'NOW DIAGRAM'
      IS(2)=IS(2)+3
      RETURN
C
C     CONVERT TO (X,Y) CO-ORDINATES
 2000 A=P*(XY(1)-XTLHC)/V1
      B=P*(XY(2)-YTRHC)/V2
      FXX=FX(A,B,P)
      IX=(FXX-XORG)*2000.
      IY=(Q-SQRT((A+FXX)*(A-FXX)))*2000.
C
      RETURN
      END
```

```
      SUBROUTINE I1
C
C     THIS SUBROUTINE READS THE VOLTAGES ON THE WIPERS OF
C     THE POTENTIOMETERS ON THE CO-ORDINATE TABLE WHEN
C     INTERRUPT 67 IS TRIGGERED FROM THE TABLE.
C
C
      COMMON /A/ IX,IY,KX,KY,IA,IB,IC(37),SF,XY(2),ILET(26),
     1NUM(10),P,ICOR,IS(15),THETA,KXD,KYD,IBF
C
  100 IS(6)=IS(6)+1
C     READ ANALOGUE VOLTAGES
      CALL RADCS (2,XY,10.0,1)
      CALL COORDS
      IF (IS(6).LE.3) RETURN
C
C     PLOT LINE
      CALL LINE (IX,IY)
      IB=IBF
C
C     IF CONTINUOUS LINE BUTTON ON THE CO-ORDINATE TABLE IS
C     PRESSED THEN READ NEXT PAIR OF VOLTAGES.
      CALL RADCS (1,V,10.0,3)
      IF (V.LE.5.0) GO TO 300
C
C     SHORT TIME DELAY
      DO 200 I=1,10000
  200 J=0
C
      GO TO 100
C
  300 ICOR=ICOR+1
C
      RETURN
      END
```

```
      FUNCTION FX(A,B,P)
C
      FX=((A+B)*(A-B)+P*P)/(P+P)
C
      RETURN
      END
```

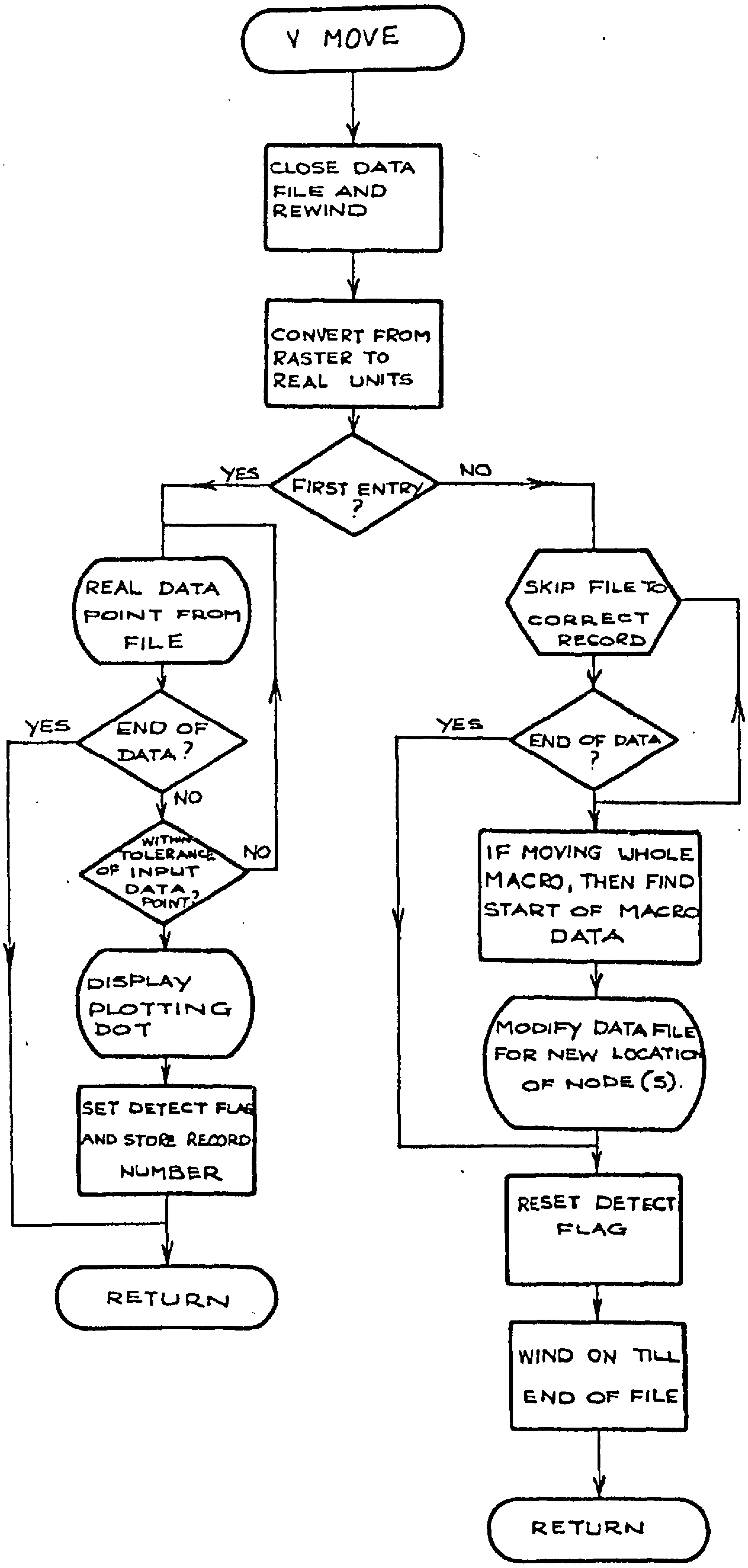
```
      SUBROUTINE I2
C
C     THIS SUBROUTINE MAKES A NO LINE, MOVE ONLY WHEN
C     INTERRUPT 68 IS TRIGGERED FROM THE CO-ORDINATE TABLE.
C
C
      COMMON /A/ IX,IY,KX,KY,IA,IB,IC(37),SF,XY(2),ILET(26),
     1NUM(10),P,ICOR,IS(15),THETA,KXD,KYD,IBF
C
      IB=2
C
      RETURN
      END
```

```
      SUBROUTINE VDU
C
C     THIS SUBROUTINE RETURNS CONTROL FROM THE CO-ORDINATE
C     TABLE TO THE VISUAL DISPLAY UNIT.
C
C
      COMMON /A/ IX,IY,KX,KY,IA,IB,IC(37),SF,XY(2),ILET(26),
     1NUM(10),P,ICOR,IS(15),THETA,KXD,KYD,IBF
C
      IB=IBF
      ICOR=ICOR+1
      CALL DISAB (2Z66,2Z67,2Z68)
      CALL ENAB (2Z64,2Z65,2Z6A)
C
C     DISPLAY CROSSWIRES
      CALL JOYSTIK (2Z65)
C
      END
```

```
!ASSIGN (M:SI,BP,SCAXPL)
!FØRTRANH GØ
    EXTENDED FIV-H, VERSIØN D00
!ALLØBT (FILE,X2),(FSIZE,55)
!ØLØAD GØ,(UDCB,5),(LIB,USER,SYSTEM);
:(FØRE,1A00),(PUBLIB,CØCLIB),(TASKS,8),(TEMP,500)
:ASSIGN (F:2,D3,JMG1)
:ASSIGN (F:5,D1,JMG2)
:ASSIGN (F:10,TK)
;ASSIGN (F:125,PRA06)
;ASSIGN (F:128,PPA06)
LØADING WAS CØMPLETED
!PAUSE PLEASE LØAD M/T JMGP
!RADEDIT
:CØPY (FILE,BT,ØV),(ØUT,BØ)
!REWIND 9TA80
       TØTAL JØB TIME .... 00:17:17
```

```
13:45 ØCT 04,'73
!JØB JMG,CADEMD
!ATTEND
!PAUSE PLEASE LØAD M/T JMGP, KEY-IN SFC
!RADEDIT
:CLEAR D3
:ALLØT (FILE,D3,JMG1),(FØRMAT,B),(RSIZE,4),(FSIZE,7000)
:CØPY (IN,9TA80),(FILE,BT,ØV)
!REWIND 9TA80
!RØV
*STØP* 0
       TØTAL JØB TIME .... 00:00:17
```


DELETE
CLOSE DATA FILE & REWIND
CONVERT FROM RASTER TO REAL UNITS
SET UP TOLERANCES
READ NEXT DATA POINT FROM FILE
END OF FILE?
YES
RETURN
NO
LINE?
NO
YES
WITHIN x & y LIMITS ?
NO
YES
WITHIN TOLERANCE OF DOT?
NO
YES
GRADIENT WITHIN TOLERANCE ?
NO
YES
N=3?
YES
NO
CHANGE LINE TYPE TO 2
N=1?
YES
DELETE WHOLE MACRO
DISPLAY PLOTTING DOT AT EACH NODE
DISPLAY PLOTTING DOT
DISPLAY HEIGHT & TYPE OF LINE
WIND ON TILL END OF FILE
RETURN


Y MOVE
CLOSE DATA FILE AND REWIND
CONVERT FROM RASTER TO REAL UNITS
FIRST ENTRY ?
YES
NO
REAL DATA POINT FROM FILE
END OF DATA ?
YES
NO
WITHIN TOLERANCE OF INPUT DATA POINT?
NO
DISPLAY PLOTTING DOT
SET DETECT FLAG AND STORE RECORD NUMBER
RETURN
SKIP FILE TO CORRECT RECORD
END OF DATA ?
YES
IF MOVING WHOLE MACRO, THEN FIND START OF MACRO DATA
MODIFY DATA FILE FOR NEW LOCATION OF NODE (S).
RESET DETECT FLAG
WIND ON TILL END OF FILE
RETURN

Loading Instructions

1. Switch on mains to the coordinate table and plug into the Sigma 5 terminal box.

2. Set Sigma 5 interface distribution board to Channel 1 and patch:

Way No.	Input
1	A/I 1
2	A/I 2
3	A/I 3
7	Int 5 (66)
8	Int 6 (67)
9	Int 7 (68)

3. Switch on paper tape punch and digital plotter.

4. Switch on the visual display unit. Set mode to 'TTY' and 'AUX' input. The shift lock should be up. Switch on joystick and adjust brightness.

5. Load short card deck (nine cards) and load magnetic tape JMGP.

6. Key-in 'SFC' on operator's console when requested.

7. The menu and crosswires should now be displayed on the screen of the visual display unit.

Operating Instructions

There is no need to use the shift key at any time during the program. When an alphanumeric character is input from the keyboard, the crosswires will disappear and the operation will then depend on which character has been input.

A HEIGHT

Message 'HEIGHT OF LINE =' will be output in the top left hand corner of the screen. Type in the height (elevation) in units of 1 thou (0.001 inches) unless metric units have been specified in '2 UNITS' (then units are microns). The maximum height is 99 thou - if this is exceeded an error message is output and the height is set to 99 thou. The input field is terminated by a carriage return. If using microns, the height is rounded down to the nearest thou.

B BRAILLE

Position the crosswires to the required beginning of the line of braille. Type in the text terminated by carriage return. The text is automatically converted to grade I braille. The cell size is determined by '1 BRL TYPE' and the angle from the horizontal for the braille text is determined by the last call to '. ANGLE'. The last character can be deleted by using the 'DEL' button and the whole line is deleted by using the 'CAN' button.

C MENU

Displays list of control commands on the right hand side of the screen.

D DELETE

Position the crosswires on the line to be deleted. This instruction will delete a whole macro but '5 QK DEL' will only delete a single element.

E END

Terminates program and returns control to operator's console. To re-run, type 'RUN OV' on operator's console.

F MOVE

Two stage command:

1. Position the crosswires on the end point of the line to be moved and press 'F'. A small spot of light will indicate that the point has been accepted.
2. Position the crosswires on the new position for the node and press 'F'.

This instruction will only move a single node but 'M MOVE' will move a complete macro.

G GEC TAPE

Generates an engraving tape for the GEC 90/2 computer.

H PT INPUT

Load paper tape (from 'P PT DUMP') into reader and press 'START' button. This instruction will cause the whole tape to be read and then displayed on the screen.

I RE-DRAW

Regenerates the display and the text is converted to braille.

J D.BOARD

This command passes control to the coordinate table. For the first time in any session do steps 1 to 3.

1. Position stylus in top left hand corner and press 'LINE'.
2. Position stylus in top right hand corner and press 'LINE'.
3. Position stylus at the origin and press 'LINE'.
4. Use 'LINE' and 'NO LINE' buttons similarily to 'L LINE' and '; NO LINE'. The computer inputs when the buttons are released. The picture is simultaneously displayed on the visual display unit. The scale is determined by 'R D.SCALE'.
5. To return control to the visual display unit press the 'END' button.

K TYPE IB

Message 'TYPE OF LINE =' in top left hand corner of the screen. Type in number, terminated by a carriage return, to determine line type:

1	solid line
3	dot
4	dotted line (.05" spacing)
5	dotted line (.15" spacing)
6	dotted line (.25" spacing)
7	dashed line (space 0.2", line 0.2")
8	dashed line (space 0.1", line 0.1")
10	dashed line (space 0.3", line 0.2")

11 dot-dash line (space 0.1", line 0.2", space 0.1", dot)

12 dot-dash line (space 0.2", line 0.4", space 0.2", dot)

L LINE

This instruction will draw a line from the previous position. The previous command should have been '; NO LINE' or 'L LINE'. The line type and elevation are specified by 'K TYPE IB' and 'A HEIGHT'.

M MOVE

Two stage command:

1. Position the crosswires on the end point of the line to be moved and press 'M'. A small spot of light will indicate that the point has been accepted.

2. Position the crosswires on the new position for the node and press 'M'.

This instruction will move a complete macro but 'F MOVE' will only move a single node.

N NEXT

This instruction clears the screen and deletes the contents of the data file. To minimise the possibility of accidental erasure of the data file, it is necessary to give this command twice.

O SCALE

This instruction changes the scale of the display (not the actual size). Message 'SCALE FACTOR =' in the top left hand corner of the screen. Type in a number terminated by a carriage return. 100 is present size, 200 is twice present size and 50 half present size etc. The grids 'V' and '3' will verify the current actual size.

P PT DUMP

Punches data on paper tape. This tape is only suitable for input using 'H PT INPUT'.

Q PLOT

Draws map full size on the digital plotter.

R D.SCALE

This instruction determines the scale from the coordinate table. Message 'D.BOARD SCALE =' in the top left hand corner of the screen. Type in a number terminated by a carriage return. 100 is 1:1 scale factor etc.

S SYM TYPE

This instruction determines the type of symbol. Message 'SYMBOL NUMBER =' in the top left hand corner of the screen. Type in the symbol number terminated by carriage return.

T SYM POS

Position crosswires. Type 'T' and symbol is drawn (symbol type is determined by the last 'S SYM TYPE' command).

U RESET

Resets all the operator-controlled variables to their default values:

height	=	10 thou
line type	=	1 (solid)
scale	=	original value
symbol number	=	1
coordinate table scale	=	1:1
braille cell size	=	English
units	=	thou

The coordinate table needs to be recalibrated.

V GRID

Draws 1" grid. The total size is 10" x 10" which is the maximum engraving area.

W SIZE

This instruction changes the actual size of the map. Message 'SIZE OF DIAGRAM =' in the top left hand corner of the screen. Type in a number terminated by a carriage return. 100 is present size etc.

X X SIZE

Same as 'W SIZE' but only affects the x axis.

Y Y SIZE

Same as 'W SIZE' but only affects the y axis.

Z FUNCTION

Message 'SPECIAL FUNCTION' in the top left hand corner of the screen. Type in a number, terminated by a carriage return, to specify the function:

1 Manhattan - makes all lines horizontal or vertical which are within 0.15 inches of being horizontal or vertical. Macros are treated as a single unit.

2 Scissor - deletes all nodes which are outside the 10 x 10 inch square.

3 Listing - prints the data file on the line printer.

1 BRL TYPE

This instruction specifies the braille cell size. Message 'TYPE OF BRAILLE' in the top left hand corner of the screen. Type in a number terminated by a carriage return:

1 American (.1" vertical, .1" horizontal)

2 English (.1" vertical, .09" horizontal)

3 Giant dot (.15" dot spacing)

4 Miniature cell (.075" dot spacing)

2 UNITS

This instruction determines whether one is working in thou or microns. Message 'INCHES OR METRIC' in the top left hand corner of the screen. Type in a number terminated by a carriage return.

1 thou

2 microns

3 CM GRID

Similar to 'V GRID' but draws a 1 cm grid (total size 10 x 10 cm).

4 CHECKOUT

This instruction will output the current values of height, units, line type, symbol number and braille cell size in the top left hand corner of the screen.

5 QK DEL

Position the crosswires on the line to be deleted. This instruction will delete a single element but 'D DELETE' will delete a complete macro.

6 D NUMBER

Message 'JOB NUMBER =' in the top left hand corner of the screen. Type in the job number terminated by a carriage return. This number is reproduced in the bottom left hand corner of the final map.

7 LETTERS

Message 'SYMBOL LETTER =' in the top left hand corner of the screen. Type in a letter. This changes the line type so that 'L LINE' positions a letter as a point symbol. The character is generated by the engraving program.

8 SYM SIZE

Message 'SYMBOL SIZE =' in the top left hand corner of the screen. Type in a number terminated by a carriage return; 100 is standard size etc. The symbols are scaled before being displayed on the screen.

9 QUADRANT

Message 'SYMBOL QUADRANT' in the top left hand corner of the screen. Type in 1, 2, 3 or 4. This determines the rotation of the symbol before it is displayed on the screen.

0 MACRO ST and - MACRO EN

A macro (group) is defined as those lines drawn between a 'MACRO START' and a 'MACRO END'.

, ORIGIN

This instruction requires two inputs. The difference in the two pairs of coordinates determines the change in the absolute origin of the map.

. ANGLE

This instruction requires two inputs. The angle between the two pairs of coordinates determines the angle from the horizontal for braille text.

; NO LINE

First point of a line.

: DIS ORIG

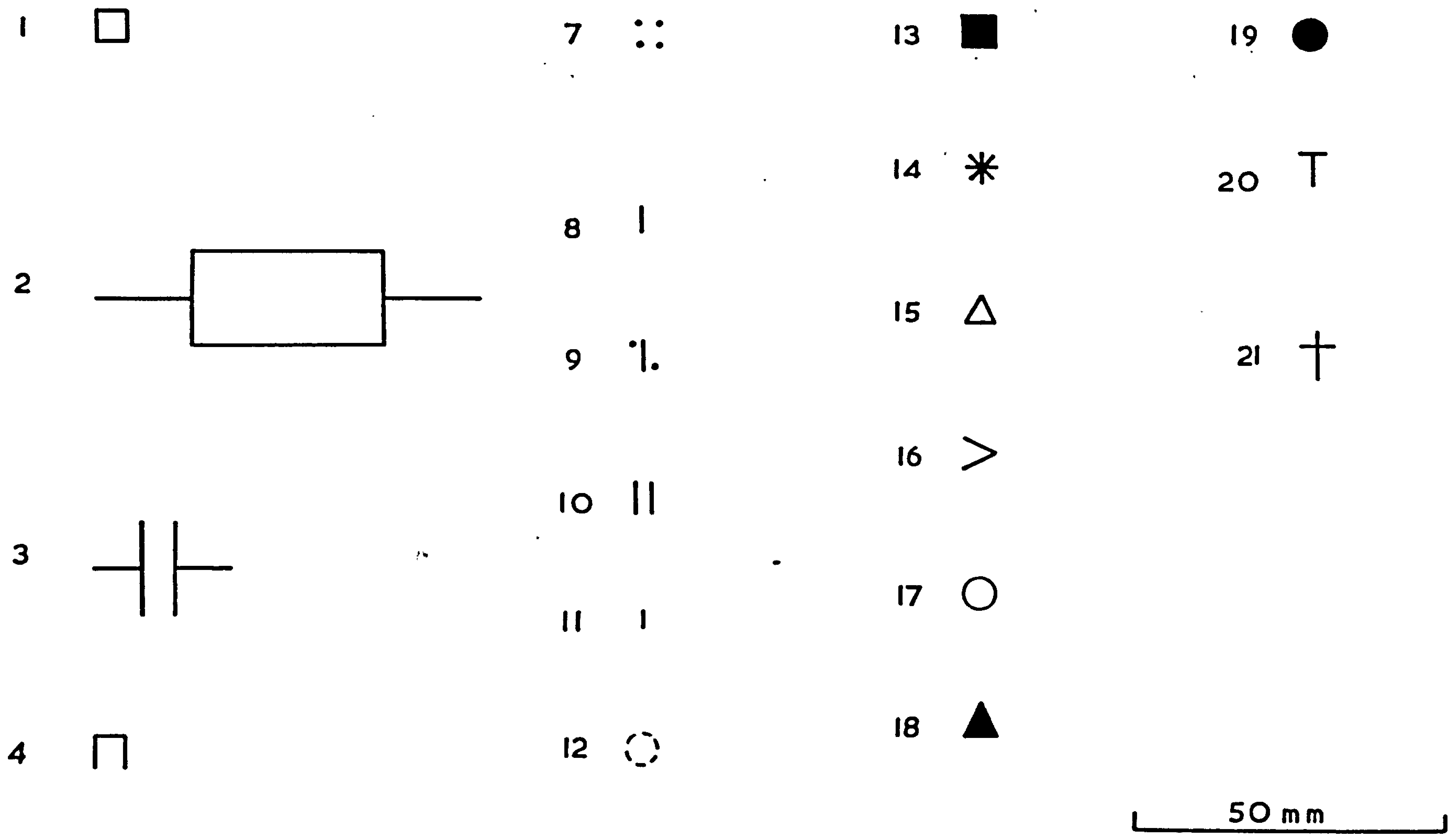
This instruction requires two inputs. The difference in the two pairs of coordinates determines the change in the display origin.

/ CHK LINE

Position the crosswires on the line. The line type and elevation are displayed in the top left hand corner of the screen.

@ DOT GRID

This instruction will draw a 5 x 5 (0.1" spacing) dot grid with the bottom left hand corner on the position determined by the crosswires.



Standard Symbols for Program CADEMD

Appendix 6. Publications

6.1 List of published and submitted papers.

"Computer production of tactile diagrams and maps". The Leonard Conference, Cambridge, England, Jan 1972, pp 73-77.

James G.A. & —— "Recent developments in the production and design of tactual maps and diagrams in the United Kingdom". International Council for the Education of Blind Youth, Madrid, 1972.

"Practical aspects of map production". Mobility Map Conference, Nottingham, England, Sept 1972.

James G.A. & —— "A pilot study on the discriminability of tactile areal and line symbols for the blind". Research Bulletin of the American Foundation for the Blind, to be published.

"A method for the production of tactual maps and diagrams". Research Bulletin of the American Foundation for the Blind, No. 26, June 1973, pp 203-204.

—— & James G.A. "A study on the discriminability of tactual point symbols". Research Bulletin of the American Foundation for the Blind, No. 26, June 1973, pp 19-34.

Douce J.L. & —— "Computer-drawn maps for the blind". Electronics and Power, Vol. 19, No. 14, August 1973, pp 331-332.

James G.A. & —— "Mobility maps for the visually handicapped: A study of learning and retention of raised symbols". Research Bulletin of the American Foundation for the Blind, to be published.

—— & James G.A. "Mobility maps: The choice of symbols". New Beacon, to be published.

"Mobility maps for the blind". Project Magazine, Central Office of Information, to be published.

Appendix 6.2

A Pilot Study on the Discriminability of Tactile Areal and Line Symbols for the Blind

To be published in Research Bulletin of the American Foundation for the Blind.

A Pilot Study on the Discriminability of Tactile Areal and Line Symbols for the Blind

by G.A. James[1] and J.M. Gill[2]

Summary

Eight tactile areal and 17 linear symbols for use on maps and graphics for the blind were produced on Brailon and tested for discriminability in separate sets by the method of paired comparisons. Subjects' response times were recorded as latencies. The results indicated that only 5 of the areal symbols but 10 of the linear symbols met the stringent criteria for discriminability suggested by Nolan and Morris (1971). Errors in discrimination are discussed with reference to the parameters which contribute to the discriminability of the symbols used in the study, and latencies are discussed in relation to 'response set'.

1. Introduction

It has been shown that there is a need for tactile maps and diagrams for blind schoolchildren. Leonard and Newman (1967 & 1970) demonstrated that at least half of the subjects in a study were able to complete an unfamiliar route with the aid of a tactile map to provide the relevant information.

Tactile maps and diagrams are composed of three categories of symbols : line symbols to designate boundaries or lines, areal or texture symbols for areas and point symbols to show specific locations or landmarks. This study is concerned only with areal and line symbols.

Several studies have attempted to define sets of discriminable tactile areal and line symbols for the blind. Heath (1958) conducted a pioneer study by examining the discriminability of 40 tactile areal symbols using the method of constant stimulus differences to compare symbols randomly grouped in sets of 10. He also found that areal symbols remained legible at a size of 50 x 50 millimetres. Culbert and Stellwagen (1963) also examined the discriminability of textural surfaces and found 11 out of 40 different patterns discriminable enough from all the others to be useful in the preparation of material such as maps for the blind. Nolan and Morris (1971) conducted several studies which represent the most

1. Blind Mobility Research Unit, University of Nottingham
2. Inter-University Institute of Engineering Control, University of Warwick

extensive source of information. Their findings show that the number of tactile areal or line symbols which are discriminable in a set may not exceed 8 or ten. They relate this perceptual limit to the parameters which distinguish tactile symbols. A flexible production system is therefore an essential requirement in varying these parameters as much as possible in an attempt to increase the number of legible tactile symbols within a set.

2. Production method

The study conducted by Heath (1958) used the Virkotype or Gestetner printing method. Wet ink print is dusted with a fine resinous powder which adheres to the wet ink and appears as a raised plastic symbol when heated. The disadvantages of this method have been stated by Nolan and Morris (1971) : the degree of relief is poor (.11 mms.), control of quality is poor and the medium deteriorates in humid conditions.

The production method used in the Nolan and Morris studies involved reproducing the symbols to be studied by photoengraving in zinc. The master was then pressed into soft plaster which was then allowed to harden. The moulds were then used as masters to produce vacuum-formed copies in plastic .20 mms. thick. Embossed symbols were produced at a relief varying from .46 mms. to .62 mms.

In this country a variety of production methods have been investigated by Pickles (1970). Briefly, this type of approach involves building up a master map, or diagram, on transparent cellulose. Various thicknesses of string and wire are used for line symbols; sandpapers, linoleum and fabrics are used for textures. The master can then be used to produce copies in Brailon on a Thermoform machine.

The production methods briefly described are generally time-consuming and therefore expensive if the cost of labour is taken into account. Recent developments at the University of Warwick are based on computer aided design principles. The relief and type of line or texture is input to a computer from a keyboard. Symbol parameters can be varied accurately to include various heights of solid, dotted, dashed and dot-dashed lines. Symbol specifications are stored by the computer. Once the symbols have been specified the master is engraved in a sheet of Tufnol by a computer-controlled machine tool. A positive copy, of the engraved master, is made using silicone rubber. Copies are produced in .18 mms. Brailon on a Thermoform machine.

This study is an initial attempt to define some of the parameters governing the discriminability of areal and line symbols produced by a computer-controlled method.

3. Method

Subjects

Sixty-two blind schoolboys were used as subjects. The age range was from 11 years 3 months to 19 years 1 month. This sample represented all braille readers who were available and in full-time education at Worcester College for the Blind. I.Q. scores, chronological ages and braille reading speeds were obtained from the school. They assessed braille-reading speed in the following way :

(i) boys read braille out loud to the whole class for 3 minutes.

(ii) a score was taken for the number of braille-lines completed.

(iii) the number of lines completed was then multiplied by 3/4 to give an average speed in pages of braille per hour.

Apparatus and selection of symbols

Figures 1 and 2 show the apparatus. A wooden board with a frame was used to hold the stimulus cards. Some previous studies have used a blind-fold to exclude residual vision of some blind subjects but this may introduce pshchological stress. Therefore, a screen with a curtained opening for the subjects' arms was used. The stimulus cards were contained in a filing tray. A stop-watch was used to record response times.

Selection of tactile symbols for testing was guided by previous research. Areal symbols were varied along the dimensions of continuous and interrupted, density of the pattern size of the figures making up the pattern, and the use of vertical, horizontal and diagonal lines to differentiate patterns. Linear symbols were continuous and interrupted, thick and thin, single and double and smooth edge and broken edge. The interrupted lines were varied with more than one spacing.

Areal and linear symbols were produced in Brailon. The areal ones were 50 x 50 mms. in size and the linear ones were 100 mms. in length.

Fig. 1. The experimental apparatus.

Fig. 2. The experimental apparatus.

Areal and linear symbols were tested in separate sets. Figures 3 and 4 show how the former were mounted side by side and the latter one above the other on stiff card 120 x 100 mm. The left/right, or up/down position of the symbols was determined randomly. The relief of the tactile symbols was 0.7 mms.

4. Design

Symbols within each separate set were compared by means of paired-comparison : each symbol in a set was compared with itself and every other. The 8 areal symbols gave 36 combinations, and the 17 line symbols gave 153 combinations. Three sample pairs of symbols were used to familiarize the subject with the procedure.

The order of presentation of the paired symbols was determined randomly.

5. Procedure

Two examiners tested the subjects. Standard instructions are shown in Figure 5. Each subject examined every pair of symbols and had to report whether they were the 'same' or 'different'. The examiner recorded the time to the nearest second from when the subject touched the stimulus card to when he made the decision. To prevent knowledge of results only one stroke of the pen was made by the examiner in a 'right' or 'wrong' column on the scoring sheet.

Total time taken to complete the test was about 40 minutes. This included three 60 second rest periods.

6. Criteria

Jenkins (1947) used the method of paired comparisons to define a discriminable set of tactile aircraft control levers. He excluded any shapes confused by more than 1% of the subjects. The effects of making an incorrect decision with aircraft controls are evident and justify the extremely stringent criteria.

Nolan and Morris (1971) report the following criteria as being the most useful in selecting discriminable tactile symbols for the blind :

(i) average confusion with other acceptable symbols must be 5% or less.

Fig. 3. Showing the position of the subject's hands for examination of the areal symbols.

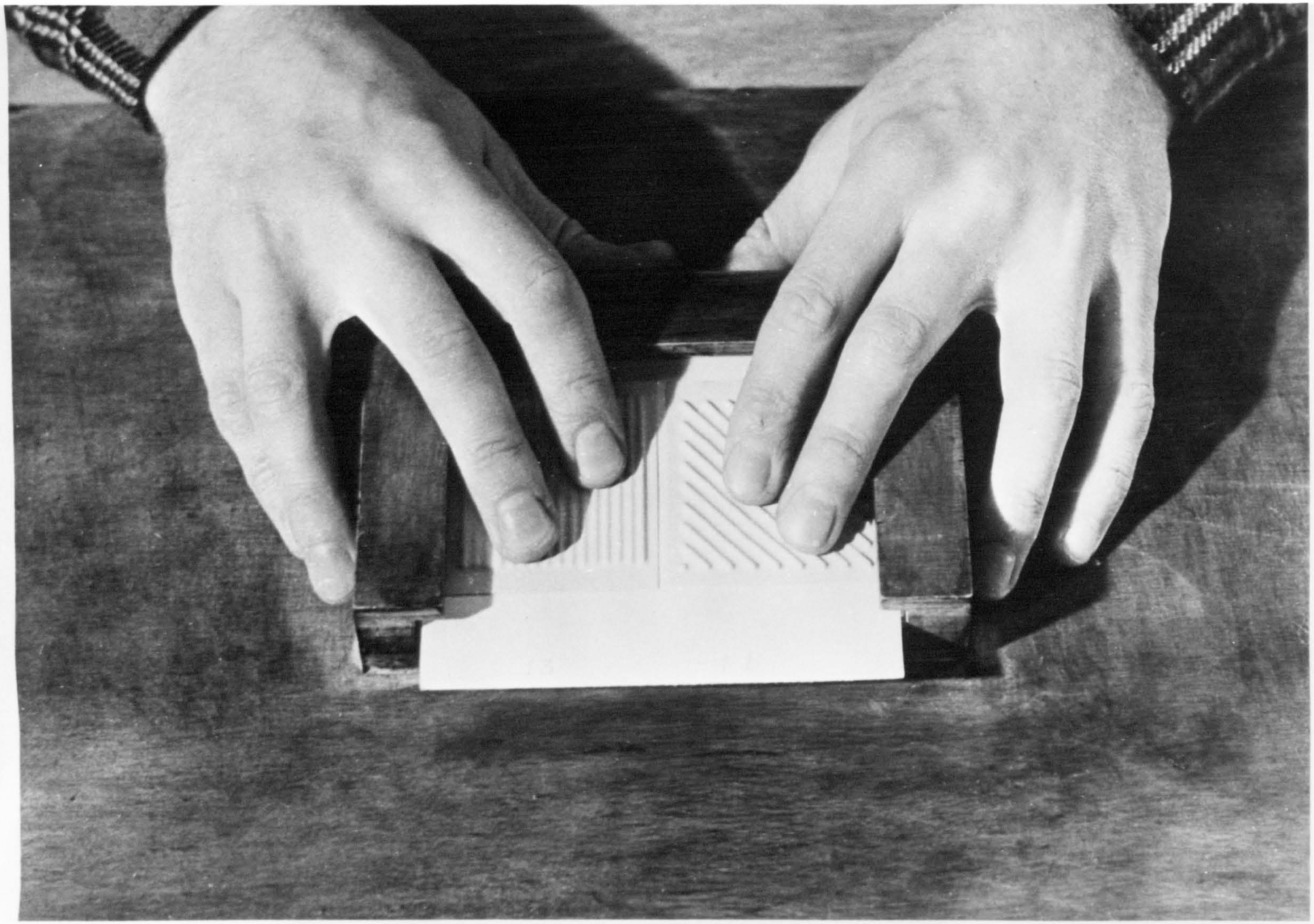


Fig. 4. Showing the position of the subject's hands for examination of the linear symbols.

FIGURE 5 STANDARD INSTRUCTIONS

TEXTURES

Please put both of your hands through the curtain on to the raised symbols in front of you. You will find two symbols side by side.

Are these symbols the same or different? (E gives knowledge of results).

There is no time limit, but remember that once you have made a decision you cannot change your mind. Give the answer "same" or "different".

We will have two more test symbols so that you have got the idea. I will tell you if you are right or wrong, but this time do not touch the symbols until I say "Now".

Are there any questions? (Questions are dealt with by repeating the relevant part of the instructions).

We are now beginning the experiment. I am not able to tell you if you are right or wrong from now on. Remember not to touch the symbols until I say "Now".

LINES

This time the two symbols are lines, and they are now one above the other. Concentrate on the centre of the lines and not the ends. First we have three test symbols so that you are sure of what you have to do. (E gives knowledge of results).

Are there any questions?

We are now beginning the experiment. I am not able to tell you if you are right or wrong from now on. Remember not to touch the symbols until I say "Now".

The experiment is much longer than the first one, so there will be two short breaks of one minute.

(ii) confusion with itself or any other single symbol acceptable by criterion (i) should be 10% or less.

(iii) any symbols acceptable by criterion (i) and (ii) must be independent of academic grade differences.

Nolan and Morris's criteria are not supported by any rationale, but as quite stringent arbitrary criteria (i) and (ii) were adopted for the purpose of this study. Criterion (iii) was not adopted because it was considered that I.Q., chronological age and braille-reading speed were more reliable variables than 'grades'.

7. Results

For the purpose of analysis braille reading speed scores were classed into frequencies as shown in Figure 6. On the basis of

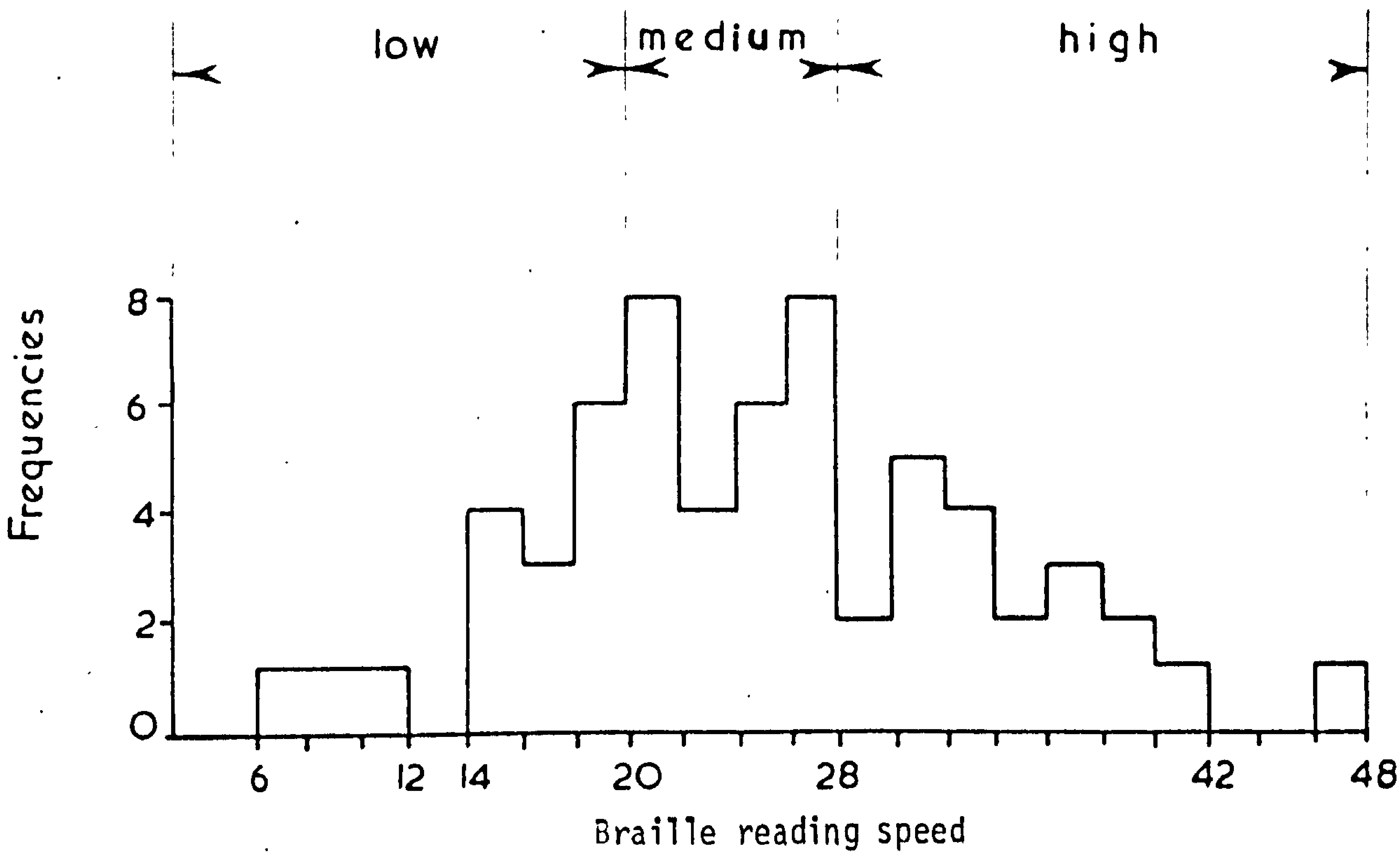


Fig. 6 Braille reading speed frequencies

these data the experimental group was divided into low, medium and high speed braille readers. Sub-groups were comprised 16, 26 and 20 subjects respectively. Tables 1 and 2 show that the mean error was no more than 2 on the areal symbols and no more than 5 on the linear ones.

Table 1 Correct responses within braille-reading speed groups for 36 combinations of 8 areal symbols

	Low	Medium	High	Total
Mean	35.12	34.53	34.75	34.80
Range	31-36	28-36	31-36	28-36
N.	16	26	20	62

Table 2 Correct responses within braille-reading speed groups for 153 combinations of 17 line symbols

	Low	Medium	High	Total
Mean	148.25	148.07	149.70	148.86
Range	141-152	131-153	143-153	131-153
N.	16	26	20	62

Krushal-Wallis one-way analyses of variance for braille reading speed groups and performance were computed separately for areal and linear symbols.. For areal symbols H was 1.00 and for linear symbols H was 2.03 - values too low to be significant at the .05 level.

No correlations were found between chronological age and performance or I.Q. and performance for areal or linear symbols.

Tables 3 and 4 show the percentage of errors for areal and linear symbols. (Areal symbols are indicated by upper-case letters and linear symbols by lower-case). After excluding B, D and H the remaining areal symbols were A, C, E, F and G and these are indicated by an asterisk in Figure 7. After excluding m, h, k, n, p, j and e the remaining linear symbols were a, b, c, d, f, g, i, l, o and q and are indicated by an asterisk in Figure 8.

Mean latencies for areal and linear symbols are shown in Tables 5 and 6 respectively. Latency differences between like and different pairs of symbols were assessed for areal and linear symbols separately. The standard mean latency for different areal symbols was 2.94 and for like pairs was 5.78, and for linear symbols the corresponding figures were 2.45 and 5.23. To give the significance of the latency differences for like and different symbols the Mann-Whitney U-test was applied and

TABLE 3. PERCENTAGE OF ERRORS ON AREAL SYMBOLS

	A	B	C	D	E	F	G	H
A	4.8	1.6	3.2	1.6	0	1.6	4.8	0
B		11.2	1.6	20.9	0	3.2	0	0
C			9.6	1.6	3.2	0	1.6	0
D				14.5	0	1.6	0	0
E					1.6	1.6	3.2	1.6
F						0	4.8	3.2
G							8	0
H								11.2

TABLE 4. PERCENTAGE OF ERRORS IN LINE SYMBOLS

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q
a	1.6	4.8	0	0	0	0	1.6	0	1.6	6.4	0	0	0	1.6	0	0	0
b		3.2	0	0	0	0	3.2	0	1.6	3.2	0	0	0	0	0	0	0
c			6.4	6.4	1.6	0	0	0	0	0	0	0	0	0	0	0	0
d				3.2	0	0	1.6	1.6	0	0	0	0	0	1.6	0	0	0
e					8.0	62.9	3.2	17.7	0	0	0	0	1.6	6.4	0	0	1
f						6.4	1.6	11.2	1.6	1.6	0	0	3.2	4.8	0	1.6	3.2
g							4.8	1.6	0	3.2	0	0	0	0	0	0	0
h								20.9	1.6	0	0	0	1.6	4.8	0	0	0
i									3.2	33.8	0	3.2	0	1.6	0	1.6	0
j										3.2	0	0	0	0	1.6	0	0
k											11.2	0	0	0	0	0	14.5
l												4.8	0	0	4.8	30.6	1.6
m													17.7	9.6	0	0	0
n														12.9	0	0	0
o															0	17.7	0
p																4.8	0
q																	8.0

TABLE 5. MEAN LATENCIES FOR AREAL SYMBOLS (SECONDS)

	A	B	C	D	E	F	G	H
A	5.89	3.22	3.45	3.09	2.32	2.48	3.08	2.22
B		6.42	2.87	6.14	2.11	2.84	3.08	1.87
C			9.13	3.05	3.08	2.00	3.30	2.88
D				6.44	2.11	2.47	2.72	2.72
E					3.26	2.90	4.19	2.56
F						4.40	3.29	3.45
G							5.42	2.98
H								5.32

TABLE 6. MEAN LATENCIES FOR LINE SYMBOLS (SECONDS)

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q
a	3.01	2.82	1.90	1.87	2.20	1.96	2.45	2.00	2.22	3.06	2.31	1.85	2.68	2.52	2.03	1.61	2.05
b		3.62	2.08	1.98	2.23	1.96	2.83	2.25	2.14	2.56	2.12	1.93	2.22	2.24	1.88	2.12	1.90
c			4.79	3.16	2.00	2.54	2.46	2.35	1.67	1.83	2.12	2.09	1.96	2.42	2.04	2.09	2.27
d				6.54	2.09	2.37	2.13	2.85	1.81	1.61	1.96	1.72	2.09	2.45	2.05	2.29	2.29
e					4.08	6.35	3.19	3.83	2.32	2.17	2.09	2.14	2.62	3.93	2.17	2.08	2.24
f						6.59	2.41	4.09	1.98	2.87	2.66	2.00	3.09	3.82	2.03	1.95	2.30
g							5.87	2.87	2.45	2.08	1.96	1.93	2.52	2.98	2.16	2.46	2.25
h								6.45	2.13	1.90	2.04	2.61	3.20	3.22	2.48	2.00	2.17
i									3.24	4.30	2.04	2.00	2.45	2.55	2.48	2.19	2.03
j										4.00	2.16	2.01	2.50	1.96	2.37	2.17	2.08
k											6.66	1.95	3.72	2.61	2.16	2.48	4.55
l												4.80	2.35	2.43	3.01	4.87	2.04
m													7.67	4.96	2.66	2.03	3.06
n														4.46	2.25	1.88	3.34
o															6.70	4.62	2.95
p																5.70	2.22
q																	4.79

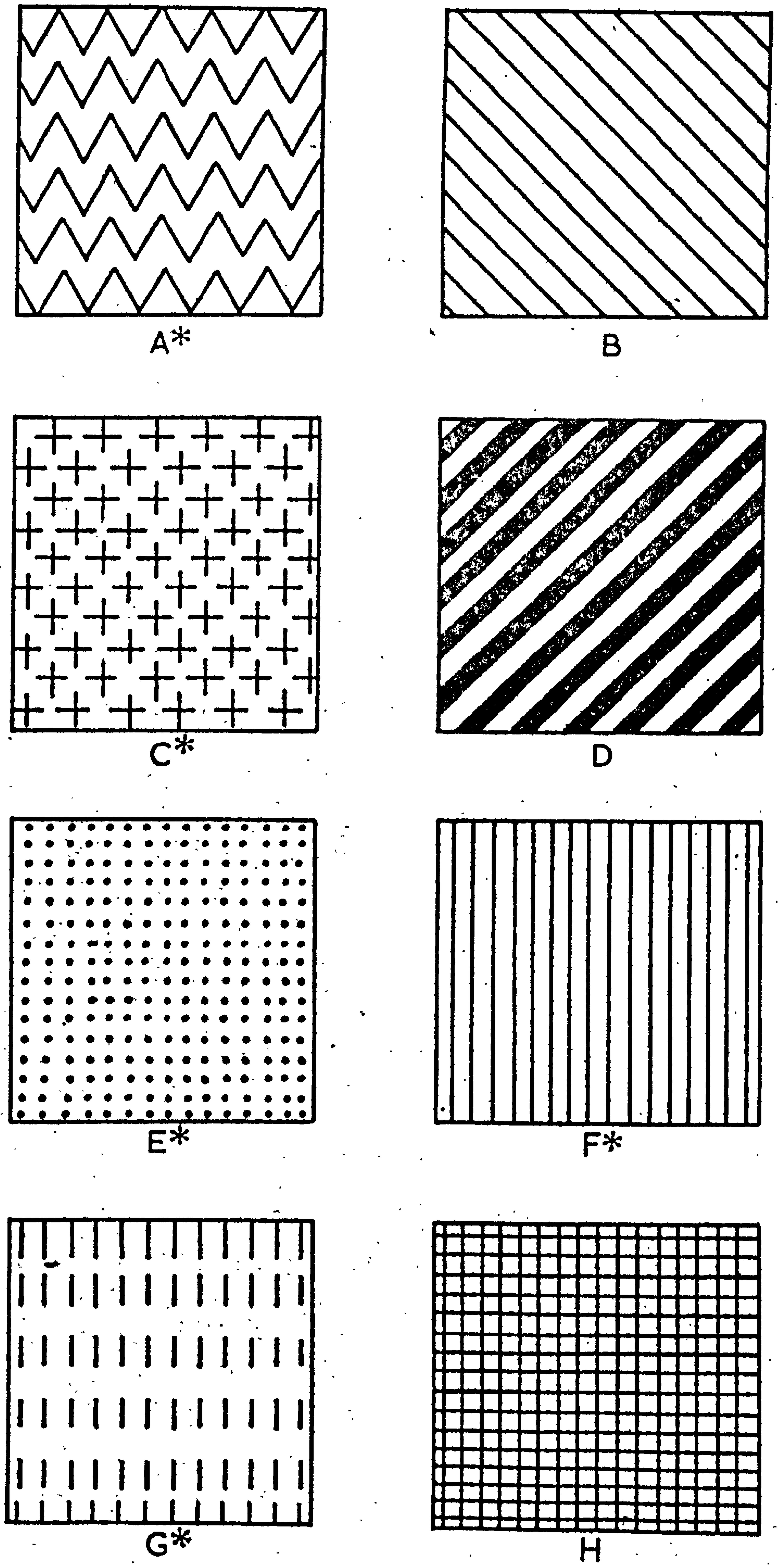


Fig. 7. The outside dimensions of the eight plastic areal symbols are 50 mm square. Asterisks identify a discriminable set.

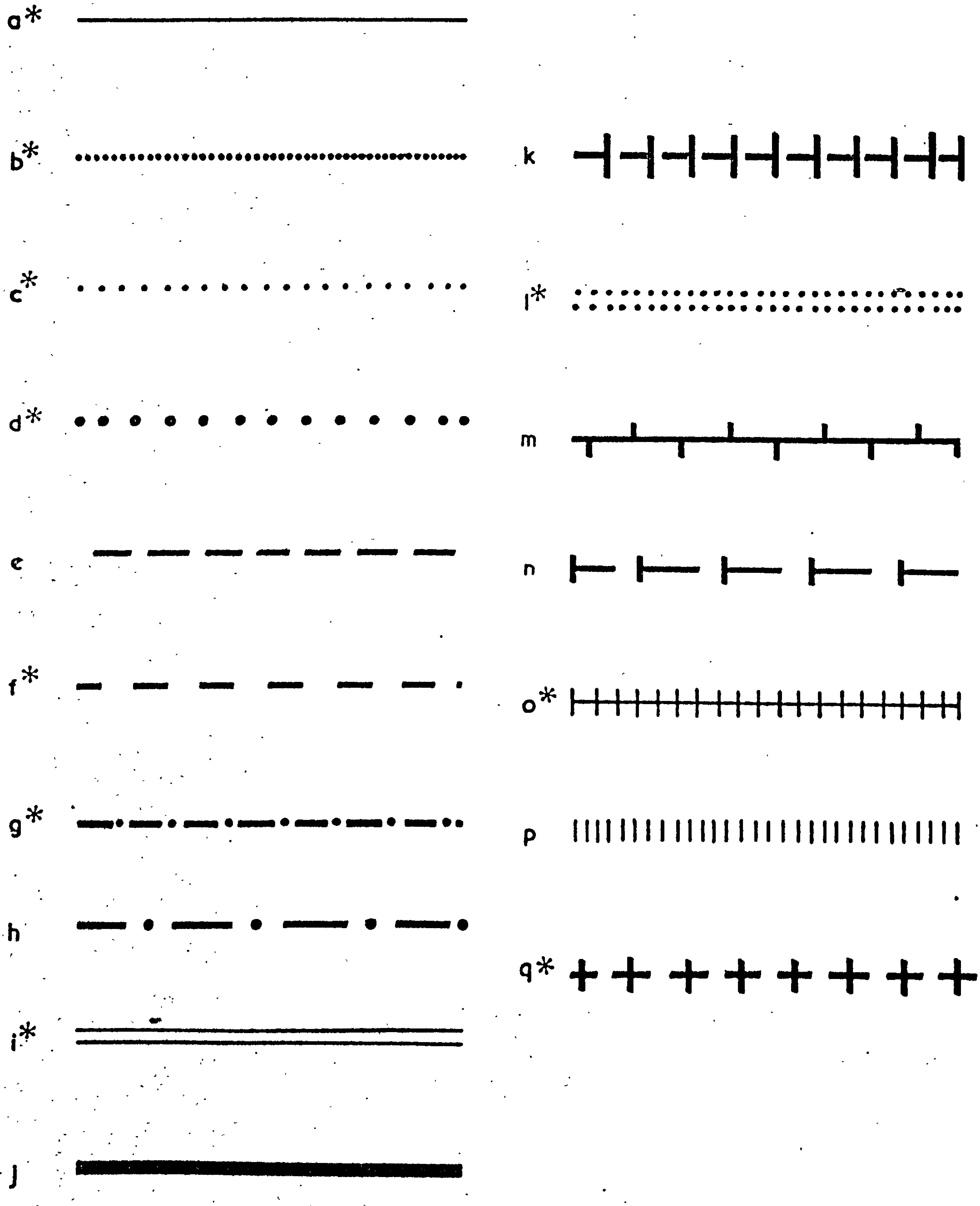


Fig.8. The seventeen linear plastic symbols are 100 mm long. Asterisks identify a discriminable set.

it was found that the differences for both areal and linear symbols were significant at less than the .001 level.

8. Discussion

The study was successful in increasing the number of discriminable tactile linear symbols from the 8 found by Nolan and Morris (1971) to 10. However, this does not exceed the upper limit of 10 suggested by Nolan and Morris and adds further evidence to the theory that there may be an inherent limitation in the variety of tactual discriminations a person can make on symbols of this kind. Alternatively, there may be limitations in the experimental design and it is hoped in future research to investigate this problem. The distinguishing parameters for linear symbols are evident from Figure 8. For interrupted lines spacing is a distinguishing parameter for dotted lines (c, d) but not for dashed lines (e, f). Lines with edges broken by vertical projections (k, m and n) are easily confused and the use of projecting lines of differing angles might be useful.

Areal symbols had a limited range, but we confirmed Nolan and Morris's finding that if the areal pattern is basically similar, as in B and D, change of direction on diagonals is not a good cue for discrimination. This is a cognitive problem and might be solved by introducing perceptual training.

One self-error in the areal symbols and 4 in the linear ones detracted from the number of legible areal and line symbols. Had it not been for these errors, 6 out of 8 areal symbols would have been discriminable and 12 out of 17 lines. One explanation for self-errors is that subjects may be examining the symbols too closely for subtle differences which do not exist, alternatively subjects have a response set for saying 'different' when in actual fact they mean 'same'.

Results for latencies oppose the 'mental set' explanation for like-pair errors. Subjects spent significantly more time discriminating like-pairs of symbols as compared with different. Although one subject did remark "It becomes mechanical after a while", the evidence shows that subjects did not continue answering 'different' when the symbols were the same.

A criticism of this study is that the symbols were presented in the same random order to each subject. In view of the length of the test (40 minutes) practice and fatigue could have been compensated for by alternating the order of presentation. A further criticism is that time-keeping by stop-watch was both tiring for the experimenters and inaccurate, and more sophisticated timing would be useful in future work.

Future work on areal and linear symbols should include a more systematic analysis of the parameters which contribute to discriminability, and a consideration of the effect of variation in symbol relief to increase information redundancy.

Immediate research includes the assessment of discriminable tactile point symbols, including upper-case letters of the English alphabet, and an examination of the usefulness of this type of tactile code for school-children and adults who are braille and non-braille readers.

Acknowledgements

The joint authors of this paper have carried out this work with the financial assistance of the Medical Research Council and the Science Research Council. The authors wish to thank their supervisors Dr. J.D. Armstrong (B.M.R.U.), and Professor J.L. Douce (I.U.I.E.C.). The authors are further indebted for the advice and suggestions of Mr. M.J. Tobin (Director of The Research Centre for the Visually Handicapped, Birmingham) and to the Headmaster and pupils of Worcester College for the Blind, England.

References

CULBERT, S.S. and STELLWAGEN W.T. (1963) Tactual discrimination of textures, *Perceptual and Motor Skills*, 16, 545-552.

HEATH, W.R. (1958) *Maps and Graphics for the Blind : Some Aspects of the Discriminability of Textural Surfaces for use in Areal Differentiation*, Ph.D. thesis, University of Washington

JENKINS, W.O. (1947) : The tactual discrimination of shapes for coding aircraft-type controls. In Fitts, P.M. (Ed.) : *Psychological Research on Equipment Design*. Washington, D.C. U.S. Govt. Printing Office.

LEONARD, J.A. and NEWMAN, R.C. (1967) Spatial orientation in the blind. *Nature*, 215, 1413-1414.

LEONARD, J.A. and NEWMAN, R.C. (1970) Three types of 'maps' for blind travel. *Ergonomics*, 13, 165-179.

NOLAN, C.Y. and MORRIS June E. (1971), *Improvement of Tactual Symbols for Blind Children*. Final Report, American Printing House for the Blind.

PICKLES, W.J. (1970) Raised diagrams pp. 118-145 in *The Teaching of Science and Mathematics to the Blind*. The Royal National Institute for the Blind. London.

SIEGEL, S., (1956), *Nonparametric Statistics for the Behavioural Sciences* (New York : McGraw-Hill Book Co., Inc.).

Appendix 6.3

A Study on the Discriminability of Tactual Point Symbols.

Research Bulletin of the American Foundation for the Blind, Number 26, June 1973, pp 19-34.

Summary

Thirty tactual point symbols were tested for discriminability by the method of pair comparisons. The 194 visually handicapped subjects included schoolchildren, adults who read braille and adults who were non-braille readers. The results indicated that 13 point symbols met the criteria of discriminability suggested by Nolan and Morris (1971).

Introduction

Tactual maps and diagrams are composed of three categories of symbols: line symbols to designate boundaries or lines, areal or texture symbols for areas and point symbols to show specific locations or landmarks. This study is concerned only with point symbols.

The three major factors influencing the discrimination of tactual symbols are:-

(i) size
(ii) height
(iii) form or configuration

(i) Size

Tactual symbols have to be constructed at a much larger size than visual ones because of the relative inadequacy of touch when compared with vision. Nolan and Morris (1971) found that symbols of 5 mm side length were considerably less confused than those at a smaller size. This prompted the recommendation that point symbols should not be smaller than 5 mm. The shortcoming of trying to define a minimum size for point symbols is that difference in size may be one of the major factors contributing to legibility among point symbols.

(ii) Height

Psychophysical studies of stimulus height or relief have been mainly concerned with the braille dot. For instance, Meyers (1955) found that differences of .025 mm between heights of neighbouring dots could be distinguished with 68% accuracy, and this improved to near 100% when the height differed by .127 mm. This indicates that variation in the height of tactual symbols may be a good distinguishing feature. Variation in height has been used to differentiate between point, areal and line symbols in the context of a tactual map (Wiedel, 1969) but not within these categories of symbols.

Schiff (1967) suggested that a pattern or a pattern unit providing differential rates of digital skin deformation gives an excellent basis for tactile discrimination in that this provides an intensity basis for tactile perception. Schiff, Kaufer and Mosak (1966) developed a tactual line whose properties specify direction such that the line felt smooth in one direction and rough in the other direction. Schiff and Isikow (1966) studied the effect of redundant information in a tactual histogram and found that a redundant presentation provided the fewest errors when size differences were small.

(iii) Form or configuration

A low twö point limen, or threshold, of touch for the fingers is important in determining the form or configuration of a tactual symbol.

Boring (1942) and Weinstein (1968) found this was 2.3 mm for static touch. This corresponds to the interdot spacing for standard braille. The two point limen is reduced if active touch is employed and allows 'microdot' braille (1.9 mm spacing) to be legible. However, braille reading speed is considerably reduced when the interdot distance is reduced to 2 mm (Calvin and Clark, 1958; Meyers, Ethington and Ashcroft, 1958).

Schiff and Dytell (1971) recommend that "although the terms tactual and tactile are used interchangeably throughout most of the literature, we suggest that tactual specify the active use of part of or the entire hand as a 'sense organ system' (Gibson, 1966), including the obtaining of stimuli from muscles and joints as well as the skin, while tactile should specify skin sensitivity per se, implying 'passive' touch (Gibson, 1962) in most cases".

Major (1898) tested both solid and outline circles and triangles. He ranked the outline circles as the easiest to discriminate and the solid circles as the most difficult. Zigler and Barrett (1927) tested solid, outline and punctate symbols and found that the outline figures gave the most accurate scores. It appears that the pad of the finger feels an outline shape more easily than a solid one, but this does not hold when the size is reduced. Austin and Sleight (1952) examined the tactile and tactual discriminability of both outline and punctate point symbols and found that outline figures with tactual reading were the most discriminable.

The two point limen of touch may be lowered by the use of active touch and by training (Boring, 1942; Weinstein, 1968). Consequently, these factors may be important in the discrimination of embossed symbols.

Nolan and Morris (1971) studied 12 point symbols embossed in plastic at 5 mm size and found 8 to be discriminable. They also tested 19 symbols embossed in paper of which the largest was 14 mm and found 11 to be discriminable. Wiedel and Groves (1969) tested 15 point symbols and found 3 to be discriminable but details of their testing procedures are not reported.

The aim of this experiment is to study the discriminability of 5 mm tactual point symbols for four groups of subjects. The four groups of visually handicapped subjects are schoolboys, schoolgirls, adults who read braille and adults who are non-braille readers. The data obtained from this experiment is to be used in the future design of tactual maps and diagrams.

1. Experiment 1

1.1 Method

Subjects

Forty-five blind schoolboys, 52 blind schoolgirls, 32 blind adults who read braille and 27 blind adults who do not read braille were used as subjects; they were not paid for their services. The adults were a convenience sample of those who agreed to be tested at various centres for the blind. The mean ages for these groups are shown in Table 1.

Table 1 Ages and length of time registered blind in years

	Boys	Girls	Adult braille readers		Adult non-braille readers	
	age	age	age	onset	age	onset
Mean	15.1	15.7	44.6	29.2	54.4	13.7
S.D.	2.1	2.0	15.8	21.4	13.4	17.1

For the schoolchildren IQ scores, ages and braille reading speeds were obtained from the schools. They assessed braille reading speed in the following way.

(i) the child read braille text out loud to the whole class for 3 minutes.

(ii) a score was taken for the number of braille lines completed.

(iii) the number of lines completed was then multiplied by 0.75 to give an average speed in pages of braille per hour.

The adults were asked for their age, date of becoming registered blind, degree of blindness and their experience with tactual maps. Braille readers were defined as those who said they were proficient grade 2 braille readers. The degree of blindness was specified as three groups - totally blind (T), perception of light (PL) and perception of hand movement (HM). Experience with tactual maps was subdivided into - a good deal (A), some (B) and very little or none (C). The results are summarized in Table 2.

Table 2 Number of adult subjects by sex, degree of blindness and experience with tactual maps.

	N	Sex		Degree of blindness			Experience with maps		
		male	female	T	PL	HM	A	B	C
Braille readers	32	18	14	23	4	5	5	12	15
Non-braille readers	27	11	16	6	7	14	0	3	24

Selection of symbols

A pilot study was conducted using symbols based on those tested by Nolan and Morris (1971), Schiff (1967), Wiedel and Groves (1969), and those in current use in Britain. Symbols consisting of groups of dots were rejected since these were considered to be multiple symbols. Fifty different symbols with a maximum side length of 5 mm were produced in 0.18 mm semi-rigid vinyl sheet with 1.5 mm relief. The symbols were vacuum-formed from a master made by a computer-aided production system (Gill, 1972).

Following a pilot study, thirty symbols were chosen for testing and divided into three groups of ten (Figure 3). The allocation into different groups was done so that symbols thought likely to be confused were in the same group.

Apparatus

The apparatus is shown in figure 1. The screen excluded the use of residual vision. The symbols were mounted 50 mm apart on three disks; 55 pairs on each disk. The disks were rotated by the experimenter so that the symbols were in the same place under the subject's fingers. The order of the pairs and the order of presenting the pairs was determined randomly. The order of presenting the disks and the direction of rotation was also determined randomly giving 18 different orders of presentation.

1.2 Design

Symbols within each set were tested by means of paired-comparison; each symbol in a set was compared with itself and every other symbol. Each group of 10 symbols gave 55 combinations. Four sample pairs, which were not included in the experiment, were used to familiarise the subjects with the procedure.

The order of presenting the disks and the direction of rotation was determined randomly.

1.3 Procedure

Three examiners tested the subjects. Standard instructions are shown in figure 2. Each subject examined every pair of symbols and had to report whether they were the 'same' or 'different'. To prevent knowledge of results only one stroke of the pen was made by the examiner in a 'right' or 'wrong' column on the scoring sheet.

1.4 Criteria

Nolan and Morris (1971) report the following criteria as being the most useful in selecting discriminable tactile symbols for the blind:

(i) average confusion with other acceptable symbols must be 5% or less.

(ii) confusion with itself or any other single symbol, acceptable by criterion (i), should be 10% or less.

(iii) any symbols acceptable by criteria (i) and (ii) must be independent of academic grade differences.

Criteria (i) and (ii) were adopted for the purpose of this study.

Figure 1. Experimental apparatus.

Fig. 2. Standard instructions

1. Please put both hands onto the two symbols in front of you (guide hands if necessary).

2. You have to say whether the two symbols are the 'same' or 'different'. You just say 'same' or 'different'.

3. There is no time limit and I will not be timing you, but remember once you have made a decision you cannot change your mind.

4. Just lift your fingers off the symbols when you have made your decision and do not put them onto the next pair of symbols until I say 'now'.

5. We will have four test symbols and I will tell you if you are right or wrong.

6. Any questions?

7. We are now beginning to experiment and from now on I cannot tell you whether you are right or wrong. Do not spend time worrying about small details. The experiment consists of three parts of about five minutes each.

1.5 Results

Tables 3–14 show the percentage of errors for the three groups of symbols for each of the four groups of subjects. Table 15 summarises the results using the Nolan and Morris criteria.

Table 3 Percentage of errors - schoolboys, symbol group A, N = 45.

	1	2	3	4	5	6	7	8	9	10
1	2.2	0	2.2	0	2.2	0	0	0	0	0
2		4.4	0	0	0	0	0	0	0	0
3			24.4	0	2.2	6.7	0	0	0	0
4				13.3	2.2	0	0	0	0	0
5					8.9	0	0	0	0	2.2
6						17.8	0	0	0	0
7							0	0	0	2.2
8								4.4	6.7	0
9									2.2	0
10										13.3

Table 4 Percentage of errors - schoolboys, symbol group B, N = 45

	11	12	13	14	15	16	17	18	19	20
11	0	0	2.2	0	0	0	2.2	0	0	0
12		6.7	2.2	0	2.2	44.4	0	0	28.9	6.7
13			4.4	0	0	0	0	0	0	0
14				8.9	4.4	0	0	0	0	0
15					4.4	2.2	0	0	0	0
16						15.6	2.2	0	15.6	17.8
17							6.7	0	2.2	0
18								11.1	0	4.4
19									2.2	4.4
20										31.1

Table 5. Percentage of errors - schoolboys, symbol group C, N = 45

	21	22	23	24	25	26	27	28	29	30
21	27.8	4.4	4.4	11.1	2.2	0	0	0	0	0
22		26.7	2.2	2.2	0	0	0	0	0	0
23			24.4	8.9	6.7	0	2.2	4.4	0	4.4
24				15.6	0	2.2	0	4.4	0	4.4
25					6.7	0	0	4.4	2.2	0
26						6.7	0	13.3	0	2.2
27							0	11.1	0	24.4
28								8.9	0	0
29									11.1	0
30										8.9

Table 6. Percentage of errors - schoolgirls, symbol group A, N = 52

	1	2	3	4	5	6	7	8	9	10
1	0	0	0	1.9	0	1.9	0	0	0	0
2		3.8	0	1.9	0	0	0	0	0	1.9
3			15.4	0	0	1.9	0	0	0	0
4				5.8	1.9	0	0	5.8	0	0
5					9.6	3.8	0	0	1.9	9.6
6						3.8	0	0	0	0
7							1.9	0	0	0
8								7.7	19.2	0
9									1.9	1.9
10										1.9

Table 7. Percentage of errors - schoolgirls, symbol group B, N = 52.

	11	12	13	14	15	16	17	18	19	20
11	1.9	0	1.9	0	0	0	1.9	0	0	0
12		1.9	0	0	3.8	50.0	3.8	1.9	17.3	5.8
13			3.8	0	0	0	0	0	0	0
14				1.9	3.8	1.9	0	0	0	1.9
15					0	1.9	0	0	1.9	1.9
16						7.7	0	1.9	7.7	11.5
17							9.6	0	5.8	0
18								11.5	0	1.9
19									5.8	5.8
20										11.5

Table 8. Percentage of errors - schoolgirls, symbol group C, N = 52

	21	22	23	24	25	26	27	28	29	30
21	11.5	0	0	1.9	1.9	1.9	0	1.9	1.9	0
22		19.2	0	0	1.9	0	1.9	0	0	3.8
23			19.2	3.8	7.7	0	1.9	3.8	1.9	11.5
24				21.2	5.8	0	0	3.8	1.9	7.7
25					3.8	3.8	0	7.7	0	1.9
26						1.9	0	5.8	0	0
27							25.0	5.8	0	34.6
28								3.8	0	1.9
29									3.8	1.9
30										3.8

Table 9. Percentage of errors - adult braille readers, symbol group A, N = 32.

	1	2	3	4	5	6	7	8	9	10
1	0	3.1	0	6.3	0	9.4	0	0	0	0
2		0	0	0	0	0	0	0	0	0
3			15.6	3.1	15.6	28.2	0	0	3.1	3.1
4				12.5	0	3.1	0	6.3	0	0
5					3.1	3.1	3.1	3.1	0	31.2
6						21.7	0	0	0	3.1
7							6.3	3.1	0	3.1
8								0	15.6	3.1
9									3.1	3.1
10										15.6

Table 10. Percentage of errors - adult braille readers, symbol group B, N = 32.

	11	12	13	14	15	16	17	18	19	20
11	9.4	6.3	6.3	3.1	0	6.3	6.3	3.1	6.3	3.1
12		9.4	3.1	12.5	6.3	65.6	0	0	25.0	21.7
13			3.1	6.3	3.1	0	3.1	3.1	0	6.3
14				9.4	9.4	3.1	0	3.1	0	0
15					3.1	3.1	0	3.1	3.1	0
16						3.1	12.5	3.1	28.2	21.7
17							12.5	6.3	9.4	6.3
18								3.1	6.3	18.7
19									9.4	6.3
20										6.3

Table 11. Percentage of errors – adult braille readers, symbol group C, N = 32.

	21	22	23	24	25	26	27	28	29	30
21	9.4	18.7	6.3	21.7	12.5	15.6	3.1	0	6.3	3.1
22		6.3	15.6	9.4	9.4	3.1	6.3	6.3	3.1	9.4
23			15.6	9.4	21.7	0	6.3	9.4	6.3	21.7
24				12.5	15.6	12.5	0	15.6	6.3	12.5
25					15.6	9.4	3.1	21.7	6.3	9.4
26						6.3	0	18.7	0	6.3
27							3.1	18.7	0	46.9
28								12.5	3.1	12.5
29									6.3	0
30										6.3

Table 12. Percentage of errors – adult non-braille readers, symbol group A, N = 27

	1	2	3	4	5	6	7	8	9	10
1	7.4	0	11.1	11.1	11.1	14.8	0	3.7	0	3.7
2		11.1	3.7	7.4	0	11.1	7.4	3.7	7.4	11.1
3			22.2	11.1	25.9	48.1	11.1	3.7	7.4	18.5
4				33.3	11.1	22.2	3.7	22.2	22.2	24.8
5					18.5	22.2	18.5	25.9	3.7	59.2
6						22.2	0	3.7	3.7	7.4
7							3.7	14.8	7.4	18.5
8								29.6	37.0	18.5
9									29.6	14.8
10										25.9

Table 13. Percentage of errors - adult non-braille readers, symbol group B, N = 27

	11	12	13	14	15	16	17	18	19	20
11	33.3	0	7.4	0	3.7	7.4	14.8	7.4	7.4	3.7
12		25.9	0	25.9	37.0	55.5	3.7	3.7	51.8	18.5
13			18.5	3.7	0	0	3.7	3.7	3.7	0
14				18.5	25.9	33.3	0	3.7	3.7	3.7
15					11.1	29.6	3.7	0	14.8	14.8
16						33.3	11.1	14.8	40.7	40.7
17							44.4	22.2	22.2	14.8
18								22.2	7.4	44.4
19									22.2	25.9
20										29.6

Table 14. Percentage of errors - adult non-braille readers, symbol group C, N=27

	21	22	23	24	25	26	27	28	29	30
21	18.5	22.2	29.6	33.3	18.5	18.5	3.7	3.7	14.8	7.4
22		51.8	37.0	29.6	22.2	3.7	0	29.6	3.7	14.8
23			62.9	18.5	40.7	7.4	25.9	29.6	3.7	44.4
24				44.4	25.9	25.9	3.7	22.2	14.8	25.9
25					29.6	22.2	18.5	22.2	14.8	22.2
26						18.5	14.8	44.4	25.9	14.8
27							18.5	33.3	3.7	66.7
28								22.2	3.7	40.7
29									25.9	3.7
30										25.9

Table 15 Mean number of errors per subject and the number of discriminable symbols in the three groups.

Group	Mean number of errors per subject	Number of discriminable symbols on the 3 disks		
		A	B	C
Schoolboys	3.6	6	6	3
Schoolgirls	3.3	8	7	5
Adult braille readers	7.1	5	6	4
Adult non-braille readers	18.2	2	0	0

2. Experiment 2

By combining the results of the schoolboys and schoolgirls, there were 7 discriminable symbols in group A, 6 in group B and 5 in group C (N = 97). The previous experiment only demonstrated that they were discriminable within their own group. In this experiment the 18 symbols were compared with the symbols in the other two groups and with themselves. This resulted in 125 pairs.

The experimental procedure was identical to the previous experiment except that only two disks were used. Thirty-eight blind school boys were used as subjects.

The results are shown in Table 16. Subjects made an average of 2.8 errors. The discriminable symbols are indicated by an asterisk in figure 3.

Table 16. Percentage of errors - schoolboys, N = 38

	1	2	4	5	7	9	10	11	13	14	15	17	19	25	26	28	29	30
1	1.5							0	0	0	2.6	0	0	0	0	0	0	0
2		3.7						2.6	0	2.6	0	2.6	0	0	0	0	0	0
4			11.2					0	0	0	0	0	0	0	2.6	0	15.8	0
5				11.9				2.6	2.6	0	0	7.9	7.9	0	0	0	0	2.6
7					1.5			0	0	0	0	2.6	0	0	0	0	0	0
9						2.2		5.3	0	0	0	0	2.6	0	0	0	2.6	0
10							9.6	7.9	0	0	0	26.3	2.6	0	0	0	0	0
11								2.2						0	0	2.6	2.6	2.6
13									3.0					0	0	0	0	0
14										4.4				0	0	13.2	0	0
15											2.2			2.6	0	0	0	0
17												8.9		0	0	0	0	2.6
19													7.4	10.5	0	0	2.6	0
25														7.4				
26															3.7			
28																5.2		
29																	8.2	
30																		8.2

Table 17 Statistical results - Spearman Correlations

Expt. No.	Subject group.	Variable/number of correct decisions.	Spearman's Rho.	t for significance of Rho.	DF	Correlations	Significance
1	schoolboys	braille reading speed	.230	1.556	43	+	No
1	schoolboys	age	-.037	-.246	43	-	No
1	schoolboys	IQ	.507	3.853	43	+	Yes $p < 001$
1	schoolgirls	braille reading speed	.030	.185	39	+	No
1	schoolgirls	age	-.060	-.428	50	-	No
1	schoolgirls	IQ	.024	.130	30		No
1	adult braille readers	age	-.417	-2.516	30	-	Yes $p < .02$
1	adult braille readers	onset of blindness	-.268	-1.526	30	-	No
1	adult braille readers	age	-.284	-1.482	25	-	No
1	adult braille readers	onset of blindness	-.059	-.294	25		No
2	schoolboys	braille reading speed	.175	1.055	35	-	No
2	schoolboys	age	-.252	-1.561	36	-	No
2	schoolboys	IQ	.393	2.56	36	+	Yes $p < .02$

Table 18 Statistical results - Kruskal-Wallis Analysis of Variance

Expt. No.	Subject Group	Variable	Kruskal-Wallis H	DF	Significance	
1	braille readers	map experience	7.853	2	yes	$p < .02$
1	braille readers	degree of blindness	2.772	2	no	
2	schoolboys	grade	.423	2	no	
1	non-braille readers	degree of blindness	2.172	2	no	

Table 19 Statistical results - Mann Whitney U test

Expt. No.	Subject Group	Variables	Mann-Whitney U	N1	N2	Significance	
1	adult braille readers.	performance of males & females.	121	18	14	No	
1	adult non-braille readers.	experience with maps/ correct decisions.	33	3	24	No	
1	adult non-braille readers.	performance of males & females.	84	11	16	No	
1	schoolchildren.	performance of females and males.	1097	52	45	No	
1	adults.	performance of braille readers and non-braille readers.	133	32	27	Yes	$p < .01$

Group A		Group B		Group C	
1*	≡	11*	>	21	+
2*	=	12	▲	22	P
3	B	13*	⊓	23	R
4	E	14*	□	24	S
5	F	15*	■	25*	U
6	H	16	◁	26*	◌
7*	I	17	Y	27	●
8	J	18	Z	28	O
9*	L	19	A	29*	C
10*	T	20	↥	30*	✳

Fig.3. The thirty point symbols. Asterisks identify a discriminable set.

3. Discussion

The statistical analysis (Tables 17–19) indicates that there is no significant sex difference in performance. Nolan and Morris's (1971) third criterion of discriminability was that there should be no significant difference in performance by academic grade. In the second experiment there was no significant correlation with grade or age for the schoolchildren although there was a significant correlation with I.Q. for the schoolboys but not the schoolgirls. Nolan and Morris (1971) found no significant difference in performance with academic grade although this was significant in an earlier experiment (Morris and Nolan, 1963).

For the adult braille readers there was a negative correlation with age. The subjective assessment by adult braille readers of their map experience provided a significant correlation with performance. It is not possible to assess whether this would also hold for the non-braille readers since very few had had any experience with tactual maps (Table 2).

The authors observed that the method of inspection varied between subjects. Some subjects just placed their fingers on the symbols but others moved their fingers round the edges and in the centre of the symbol. The latter group seemed to perform better than those who used just passive touch. This agrees with the findings of Austin and Sleight (1952).

Jansson (1972) found that the following kinds of point symbols are often confused:

1. Evenly embossed surfaces of different form
2. Closed contours of different form
3. Open contours of different form
4. Combinations of similar units

The last group was excluded from this experiment.

In this experiment, ten of the discriminable symbols were of the open contour type while two were of the closed contour type and only one was an evenly embossed surface.

The use of the method of paired-comparison for studying the discriminability of tactual symbols has been questioned by Schiff (1967):

"The method of paired-comparison yields results of limited value in tactile discrimination studies related to diagrammatic presentation of information, since it leads one to assume better discriminability than actually present, because as amount of information to be discriminated is increased, lines or symbols of other sorts lose their discriminability".

In a tactual map a point symbol is usually used in context; for instance in a street map a roundabout only occurs at a road junction. This means that a symbol may be discriminable in context on a map although it was not found to be discriminable in a paired-comparison experiment.

Another disadvantage of using the method of paired-comparison is that the number of tests is $N(N + 1)/2$ where N is the number of different symbols to be tested. In order to keep this experiment to a reasonable length it was necessary to split the symbols into three groups of ten. This still gave 165 tests per subject and meant that the whole experiment required 30490 tests. The monotony of the experiment may have caused an increase in the number of errors.

In the second experiment 'test-retest' was used on the like pairs for 20 subjects but the sample size was too small to use this as a measure of the precision of the experiment.

This experiment has demonstrated that 13 point symbols can be discriminated by the blind school children used as subjects. It must be taken into account that the experiment only used symbols in one size, at one elevation and in one orientation. If multi-height and variation in symbol size are included then the set of discriminable symbols may be increased in number. The experiment did not study the discriminability and minimum spacing of the symbols when used on a tactual map in the presence of 'noise'.

For over a decade research has been carried out on the discriminability of tactual symbols but the symbols have not been chosen by any scientific analysis of their structure. Future work should involve more imaginative design of symbols and their discriminability should be analysed in the context of a tactual map or diagram.

Acknowledgements

The authors have carried out this work with the financial assistance of the Medical Research Council and the Science Research Council. The authors would like to thank Dr. J.D. Armstrong and P. Willans (B.M.R.U.), Prof. J.L. Douce (I.U.I.E.C.) and Dr. M.J. Tobin (R.C.E.V.H.). They would also like to thank the subjects who came from Worcester College for the Blind, Chorleywood College for Girls with Little or No Sight, Royal Midland Institute for the Blind, Guide Dogs for the Blind Association Leamington Spa Training Centre, City of Birmingham Workshops for the Blind, Royal National Institute for the Blind Clifton Spinney Rehabilitation Centre and Royal Leicester, Leicestershire and Rutland Incorporated Institution for the Blind.

Bibliography

Austin T.R. & Sleight R.B. "Accuracy of Tactual Discrimination of Letters, Numerals and Geometric Forms".

J. Exptl. Psychol., vol. 43, 1952, pp 239-247.

Austin T.R. & Sleight R.B. "Factors Related to Speed and Accuracy of Tactual Discrimination".

J. Exptl. Psychol., vol. 44, 1952, pp 283-287.

Berla' E.P. "Behavioral Strategies and Problems in Scanning and Interpreting Tactual Displays".

New Outlook for the Blind, vol. 66, 1972.

Boring E.G. "Sensation and Perception in the History of Experimental Psychology".

New York: Appleton, 1942.

Calvin J.S. & Clark J. "Influence of Type Characteristics on Braille Reading".

Unpublished manuscript, American Printing House for the Blind, 1958.

Dreyfuss H. "Symbol Source Book".

McGraw-Hill, 1972.

Gibson J.J. "Observations on Active Touch".

Psychological Review, vol. 69, 1962, pp 477-491.

Gibson J.J. "The Senses Considered as Perceptual Systems".

Boston: Houghton Mifflin, 1966.

Gill J.M. "Computer Production of Tactile Diagrams and Maps".

The Leonard Conference, Cambridge, England, Jan. 1972, pp 73-77.

James G.A. "Problems in the Standardisation of Design and Symbolisation in Tactile Route Maps for the Blind".

New Beacon, vol. 56, No. 660, April 1972, pp 87-91.

Jansson G. "Symbols for Tactile Maps".

In Lindqvist B. & Trowald N. (Eds) European Conference of Educational Research for the Visually Handicapped. Project: PUSS: VIII Report No. 31, 1972, pp 66-73.

Major D.R. "Cutaneous Perception of Form".
Amer. J. of Psychol., vol. 10, 1898, pp 143-147.

Meyers E. "July Progress Report".
Unpublished Report, American Printing House for the Blind, 1955.

Meyers E., Ethington D. & Ashcroft S. "Readability of Braille as a Function of Three Spacing Variables".
J. of Applied Psychol., 1958, vol. 42, pp 163-165.

Morris J.E. & Nolan C.Y. "Minimum Sizes for Areal Type Tactual Symbols".
Internatl. J. for the Education of the Blind, vol. 13, No. 2, Dec. 1963, pp 48-51.

Nolan C.Y. & Morris J.E. "Improvement of Tactual Symbols for Blind Children".
Report of Dept. of Health, Education, and Welfare. Project No. 5-0421, 1971.

Pick A.D. & Pick H.L. "A Developmental Study of Tactual Discrimination in Blind and Sighted Children and Adults".
Psychonomic Science, vol. 6, 1966, pp 367-368.

Schiff W. & Isikow H. "Stimulus Redundancy in the Tactile Perception of Histograms".
Internatl. J. for the Education of the Blind, vol. 16, 1966, pp 1-11.

Schiff W., Kaufer L. & Mosak S. "Informative Tactile Stimuli in the Perception of Direction".
Perceptual and Motor Skills, vol. 23, (Monograph Supplement 7), 1966.

Schiff W. "Using Raised Line Drawings as Tactual Supplements to Recorded Books for the Blind".
Final Report, RD-1571-S, Recordings for the Blind, New York, June 1967.

Schiff W. & Dytell R.S. "Tactile Identification of Letters: A Comparison of Deaf and Hearing Children's Performances".
J. of Exptl. Child Psychol., vol. 11, No. 1, Feb. 1971, pp 150-164.

Siegel S. "Nonparametric Statistics for the Behavioural Sciences".
New York: McGraw Hill, 1956.

Weinstein S. "Intensive and Extensive Aspects of Tactile Sensitivity as a Function of Body Part, Sex and Laterality".

In D.R. Kenshalo (Ed) The Skin Senses. Springfield, Illinois: Charles C. Thomas, 1968, pp 195-222.

Wiedel J.W. & Groves P.A. "Tactual Mapping: Design, Reproduction, Reading and Interpretation".

Final Report RD-2557-S, 1969, Dept. of Health, Education and Welfare.

Zigler M.J. & Barrett F. "A Further Contribution to the Tactual Perception of Form".

J. Exptl. Psych., vol. 10, 1927, pp 184-192.

Appendix 6.4

'Mobility Maps' for the Visually Handicapped:
A Study of Learning and Retention of Raised Symbols.

To be published in Research Bulletin of the American Foundation for the Blind.

'Mobility Maps' for the Visually Handicapped: A Study of Learning and Retention of Raised Symbols.

G.A. James[1] and J.M. Gill[2]

Summary

Twenty-five visually handicapped schoolchildren participated in a paired-associate learning experiment. S's had to learn the meanings of 14 different tactual symbols to a criterion of two errorless trials. Retention was measured by the savings method and the results showed a savings of 40.2%. Total percentage error scores showed that some symbols were easier to learn than others; these differences are explained in terms of symbol discriminability and information content. A further experiment showed that S's could locate and identify these symbols in the context of a map. No significant differences in the number of correct symbols identified were found between S's using a key and those using memory alone.

[1] Blind Mobility Research Unit, University of Nottingham.

[2] Inter-University Institute of Engineering Control, University of Warwick.

1. Introduction

In many situations a tactual map will provide information to visually handicapped persons more effectively than a verbal map. Many of these situations have yet to be defined. However, at a practical level some teachers have found tactual maps to be a viable means of teaching visually handicapped students orientation and mobility skills or reinforcing environmental concepts. Tactual maps used for this purpose are commonly known as 'mobility maps' in Britain and 'travel maps' in the United States. Leonard and Newman (1970) and Bentzen (1972) have shown experimentally that mobility maps can present information allowing highly mobile visually handicapped persons, who are also braille readers, to travel in unknown environments.

Listing the useful environmental features for orientation and navigation by the visually handicapped has been undertaken in two recent studies (James, 1972 and James, Armstrong and Campbell, 1973). In the first of these studies the problems of representing environmental information on tactual maps was discussed. Two of these problems will be briefly discussed here.

First, empirical studies of tactual symbols of areas, lines and points have indicated that there are a limited variety of tactually distinctive symbols that can be produced within these classes (Nolan and Morris, 1971; James and Gill, 1972; Gill and James, 1972). Nolan and Morris (1971) have stated that "until an inventory of greater numbers of legible symbols is accumulated, the potential for standardisation is limited". These studies, done by the paired-comparison method, only tested discrimination and did not test the possible improvements that perceptual training may have on performance.

Second, mobility maps are generally hand-made at a local level sometimes employing volunteer help. Different production methods and different materials are used from one locality to another. As yet, no study has been made of the different qualities and forms of symbols that can be made by these different methods.

In spite of these two problems there has been a frequent plea amongst teachers and the visually handicapped map users for some agreement on the symbols to be used on mobility maps. Some conventional users of symbols would save the map-maker from developing his symbols from trial and error but would still give him scope for making improvements; moreover, a visually handicapped map-user would be able to familiarise himself with some basic symbols and would not be required to learn a new code for every different map he encountered.

Sighted map-readers do not understand the great variety of symbols found on print maps by a process of 'common sense' but through familiarity with conventional symbols which often contain several points of information. The distinctive information properties of symbols can facilitate the learning and retention of their meanings.

Foulke and Morris (1961) and Nolan and Morris (1963) used paired-associate learning tasks to assess the learning and retention of associations between tactual symbols and verbal responses. Both studies indicated that associations could be learnt easily and retained at a fairly high level.

In order to extend the approach made by these paired-associate learning studies to cover a more practical problem, tactual symbols were chosen from those in common use to represent different environmental features or landmarks used by the visually handicapped for orientation and navigation. An experiment was designed to discover how easily the chosen symbols could be associated with their meanings and how well the associations could be retained in the memory over a period of time. Information was also sought concerning the relative confusability of the symbols and the principles which determine good legibility. Finally, it was hypothesized that once symbols and their meanings had been learnt they could be identified on a tactual map without recourse to a key.

2. Method

The total duration of the experiment was 43 days involving three separate experimental sessions.

2.1 Session 1: the initial learning phase.

Fourteen different symbols were produced using a computer-assisted production system (Gill, 1972). Plastic copies were vacuum-formed in Brailon which is a semi-rigid calendered vinyl 0.2 mm thick. The relief of line symbols was 1 mm and point symbols 1.5 mm. Line and point symbols were combined to represent some features. Print outlines of the symbols used are shown in Figure 1. The tactual symbols were mounted on stiff card 150 x 100 mm. Instructions (see Appendix 1) were presented to the subjects on a magnetic tape recording. Subjects received randomly ordered symbols to a maximum of 10 trials so that each symbol could be inspected 10 times. On the words "next symbol" the subject received a symbol and had 10 seconds to inspect it before the association words were heard from the tape recorder. After examining each symbol and hearing its meaning once, S's were required to give these association words before they were heard from the tape recorder. The criterion for completion of the task was two errorless trials, each trial consisting of the 14 symbols.

2.2 Session 2: relearning phase.

Twenty-one days after the learning phase of the experiment, a further session was conducted to assess the subjects' recall of symbol associations and 'savings' on retention. The procedure was identical to the first session.

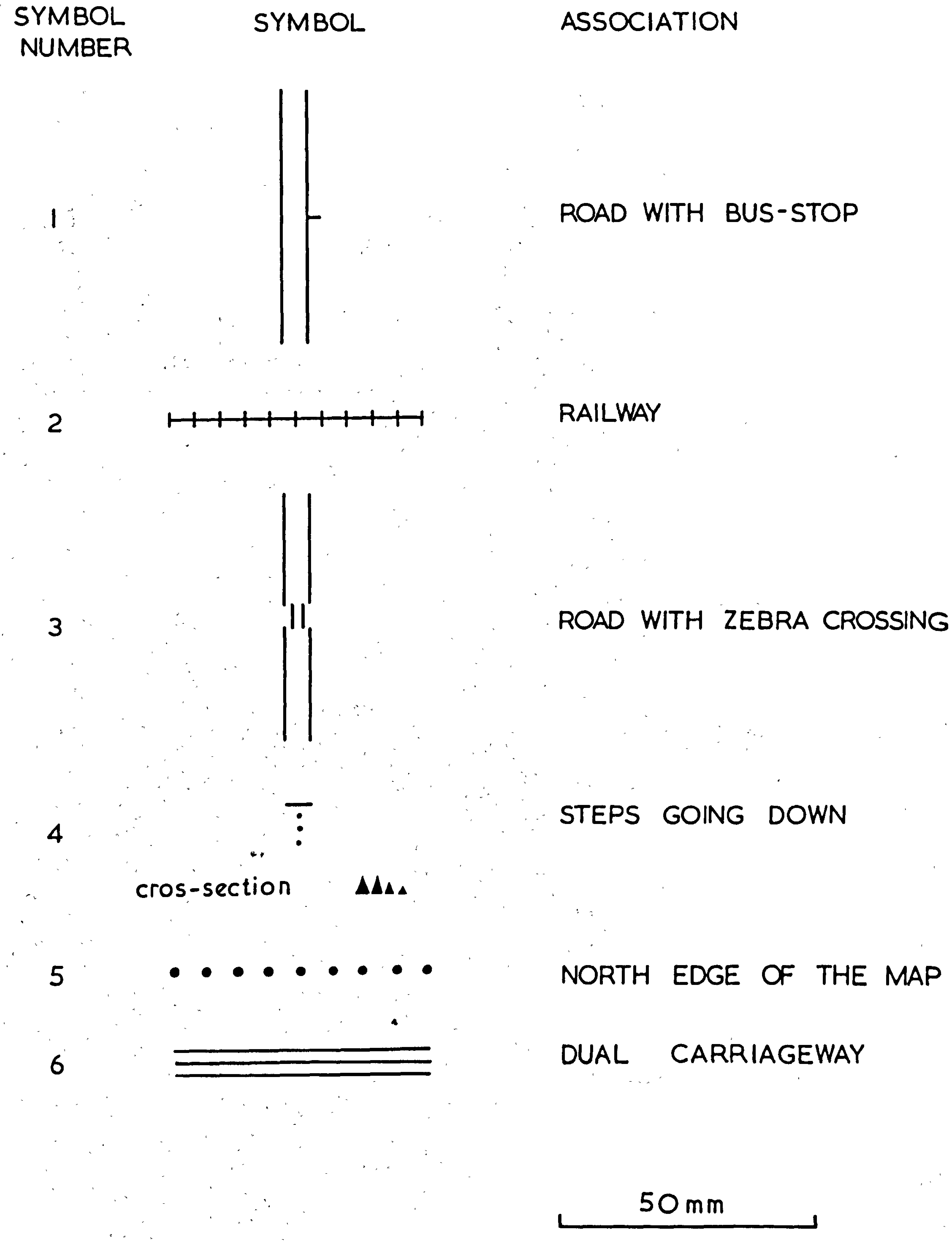
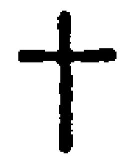
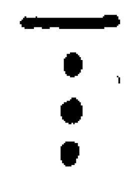
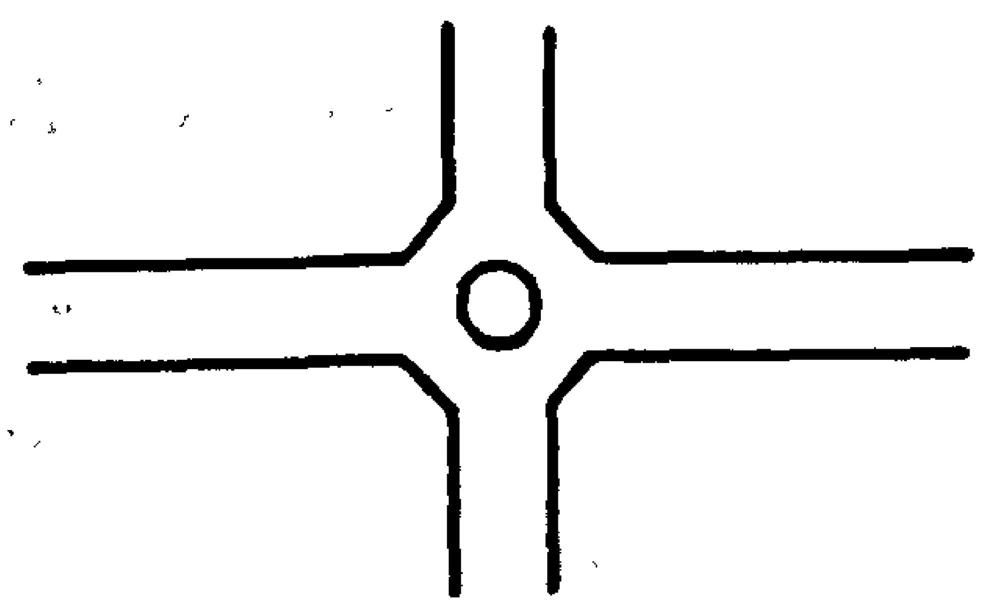
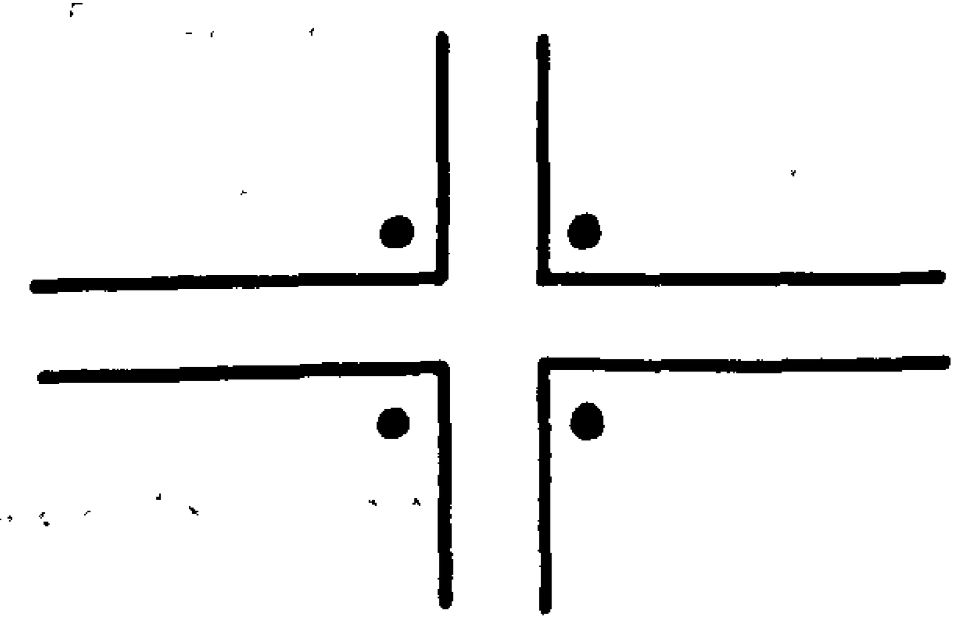


FIG. 1a. Print outlines of the tactual symbols presented to the subjects.

SYMBOL NUMBER	SYMBOL	ASSOCIATION
7		FOOTPATH
8		CHURCH
9		STEPS GOING UP
	cross-section 	
10		ROAD GOING UPHILL
11		BUILDING WITH ENTRANCE
12		CROSSROADS WITH ROUNDABOUT
13		CROSSROADS WITH TRAFFIC LIGHTS
14	T	TOILET

50 mm

FIG. 1b. Print outlines of the tactual symbols presented to the subjects.

2.3 Session 3: identifying symbols on a tactual map.

After a further period of 21 days subjects were assigned to one of two matched groups on the basis of their recall scores from the previous session. One group was randomly designated the Key Group (K) and the other the No Key Group (NK). Subjects in both groups were given a tactual pseudomap displaying all the symbols used previously (Fig. 2). Group K were also given two pages of Brailon showing the 14 tactual symbols with the associations in braille. Group NK was asked to identify the symbols on the pseudomap from memory. Instructions for this task are shown in Appendix 2.

3. Subjects

Subjects were 25 visually handicapped schoolchildren. One subject was unavailable for the second session and 4 were unavailable for the third session. Eight of the subjects were girls and the remainder boys. Only one subject relied on some residual vision to aid tactual inspection of the symbols. The sample included a range of ages from junior to secondary level (mean age = 11.54 yrs., range 7.41 - 17.66 yrs., S.D. = 3.05).

IQ scores for 21 of the subjects were obtained from the school (mean IQ = 100, range75 - 144, S.D. = 13.91). IQ had been measured by the Williams IQ test for the visually handicapped (Williams, 1956). The authors would like to point out that although the majority of the IQ scores were obtained within the last 2 years, one student was tested as long as 10 years ago. One of the items commonly used in the Williams test is a digit span of apprehension. This test was administered at the school by the authors and consisted of reading lists of

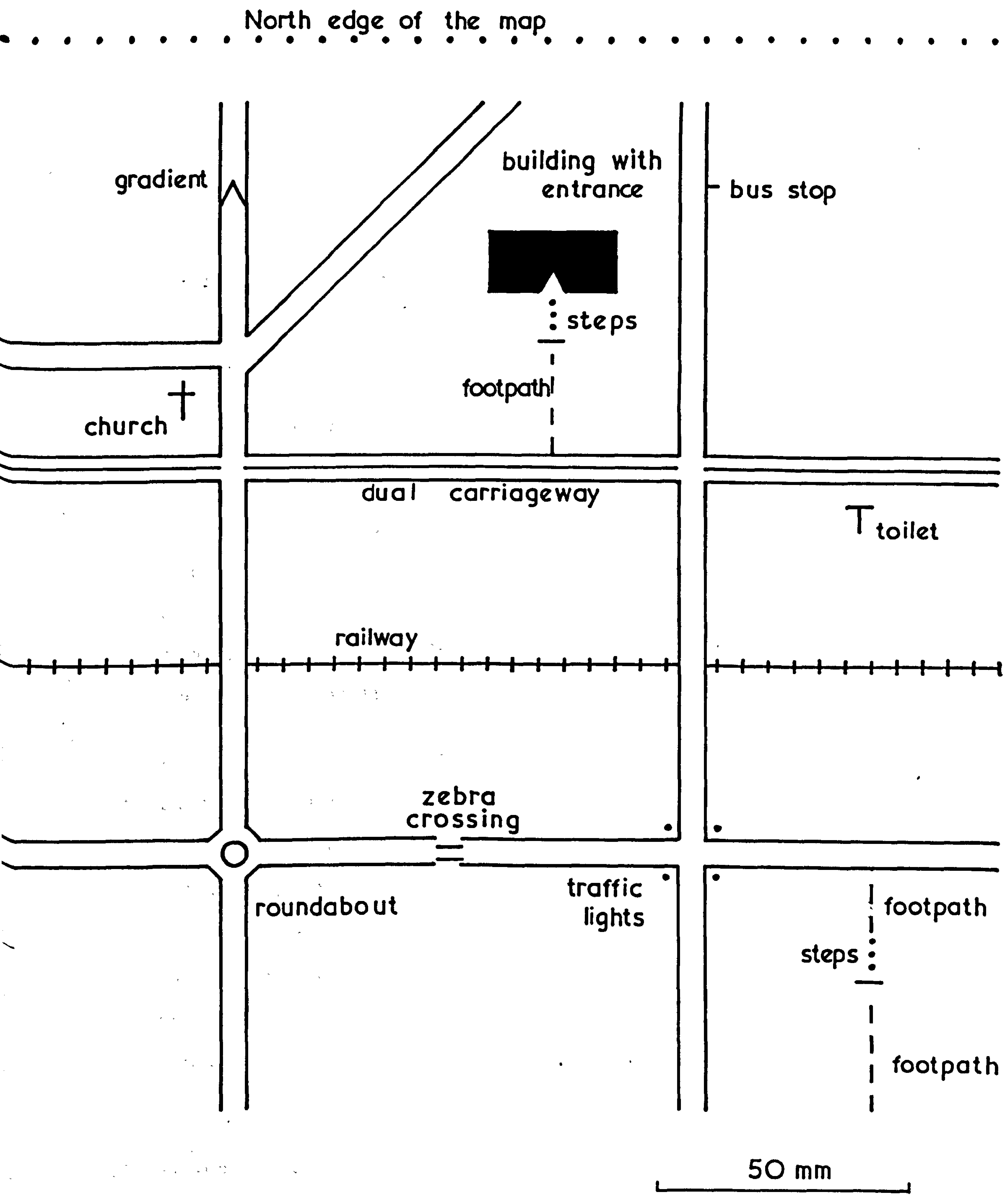


FIG. 2. Pseudomap used for the evaluation of symbols in the context of a map.

digits and asking the subject to repeat them correctly in the same order (Woodworth and Schlosberg, 1955, page 696). The mean score was 3.3 digits (range 1.5 - 5.5, SD = .97).

4. Results

The results of the experiment were scored on several dependant variables; in addition, correlations were computed to assess the effects of several independent variables (Table 1).

Six subjects in the learning trials and 1 in the relearning failed to reach the set criterion of 2 errorless trials.

Figure 3 shows the two learning curves for the learning and relearning sessions. As some subjects failed to reach the criterion alternative methods of plotting the learning curves were not attempted. Only one subject was responsible for the error rate from trial 5 to 10 on the relearning curve.

S's took a mean of 6.83 trials (SD = 2.1) for the learning phase and 4.08 trials (SD = 1.8) for relearning; this gives a savings of 40.2%. The percentage error, out of total responses, for each symbol is shown in Figure 4 and indicates considerable variability among error rates for different symbols. Differences between the percentage errors for the learning and relearning sessions are more apparent than suggested by the savings score.

Table 2 shows a confusion matrix compiled from data for incorrect responses given by the subjects. The scores for the two matched groups who had to identify symbols on a pseudomap are shown in Table 3.

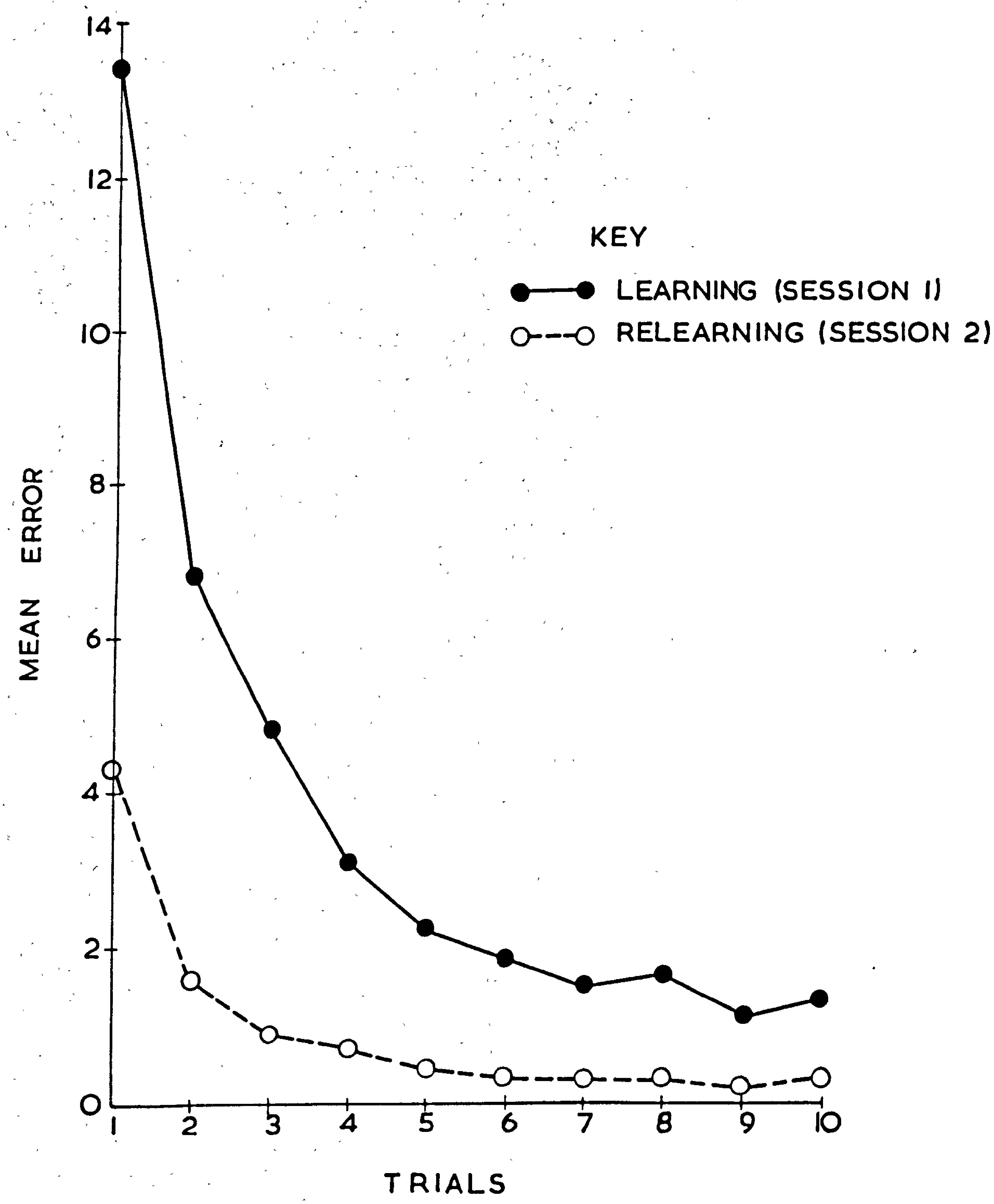
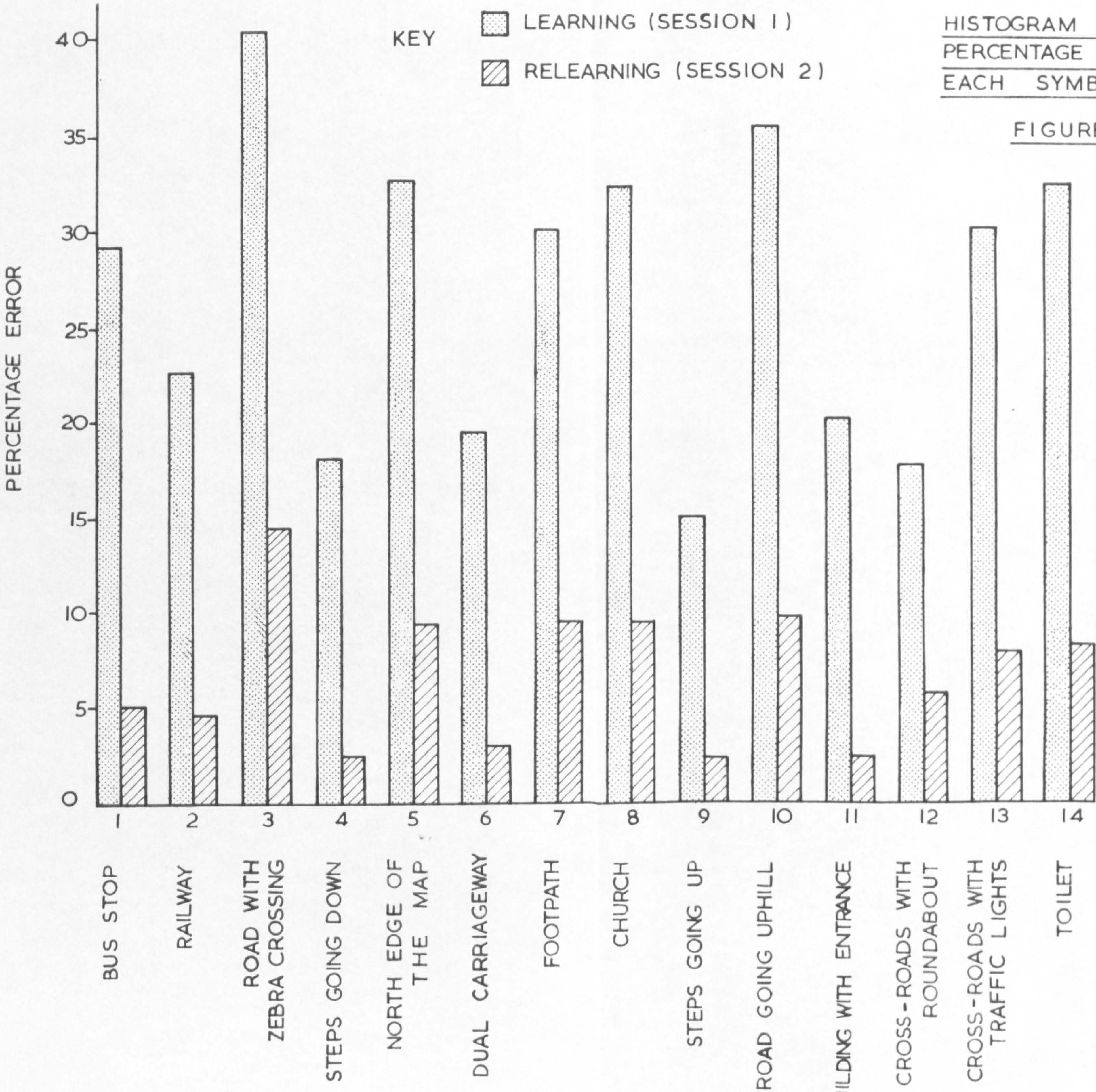


FIGURE. 3. COMPARISON OF LEARNING CURVES.



HISTOGRAM SHOWING PERCENTAGE ERROR FOR EACH SYMBOL.

FIGURE. 4.

Table 1. Statistical results, Spearman correlations.

Session number	Variables	Spearman's Rho	t for significance of Rho	DF	Significance and correlation
1	age/no. of trials	- .21	- 1.01	22	No -
1	age/no. of errors	- .27	- 1.31	22	No. -
2	age/no. of trials	- .18	- .88	22	No -
2	age/no. of errors	- .22	- 1.06	22	No -
3	age/no. of errors	- .35	- 1.65	19	No -
1	IQ/no. of trials	- .14	- .61	19	No -
1	IQ/no. of errors	- .25	- 1.16	19	No -
2	IQ/no. of trials	- .04	- .20	19	No -
2	IQ/no. of errors	- .25	- 1.16	19	No -
3	IQ/no. of errors	.06	.26	17	No +
1	STM/no. of trials	.05	.27	22	No +
1	STM/no. of errors	- .02	- .12	22	No -
2	STM/no. of trials	.02	.13	22	No +
2	STM/no. of errors	- .01	- .07	22	No -
3	STM/no. of errors	- .21	- .97	19	No -

Table 2. Confusion matrix (learning and relearning trials combined).

SYMBOLS PRESENTED

REPLY FROM SUBJECT	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1		.2	2.2		.4	.2	.6	.2		2.0				
2					1.8	1.2	3.3							
3	1.0									2.7			.8	.2
4								1.2	2.0					1.8
5		.6					1.8	.2		.2				
6		.4			.4		.4				.2			
7		2.2			2.9	.2								
8				.2										3.1
9		.2		2.0				.6						1.4
10	.8		3.5					.2				.8		
11				.2										
12			.2					.6		.8			1.4	
13	.2		.8	.2				.2		1.2		1.0		
14	.2			.2	.2			1.4	.2		.2			
	bus stop	railway	road with zebra crossing	steps going down	north edge of the map	dual carriageway	footpath	church	steps going up	road going uphill	building with entrance	crossroads with roundabout	crossroads with traffic lights	toilet

Table 3. Mean correct scores and ranges for the two matched groups for identifying symbols on a pseudomap.

Group	N	mean	range
K	10	12.4	9 - 14
NK	11	10.63	2 - 14

The data for this analysis were negatively skewed (-1.75) and although mean scores are used for descriptive purposes a nonparametric test, the Mann-Whitney U test (Siegel, 1956), was computed to test for any significant difference between the two groups. Since the value of U was 32 which was not equal or less than the critical value of 12, the null hypothesis was supported. There was no significant difference between groups K and NK.

5. Discussion

At its inception, it was hoped that this study would throw some light on the developmental problems accompanying the use of tactual maps in schools for the blind. However, the correlations between various independent variables (Table 1) were not significant and no firm conclusions can be made. With a larger N it should be possible to identify what Berla' and Nolan (1972) have recently called the 'developmental norms for tactual perceptual memory span'.

The lack of significant age/IQ correlations with performance over a wide age range may have an explanation in the particular school system. Children who have greater academic potential usually leave the school at the age of 11 to continue their education elsewhere. This factor may account for the apparent similarity in symbol learning performance between junior and secondary schoolchildren. Usually children receive no experience with tactual maps until the secondary school, which suggests that there is considerable unrealised potential in the junior school if map reading can contribute significantly to a visually handicapped child's education.

No previous studies of tactual stimulus memory span have presented to subjects as many as 14 different stimulus items. In view of the large number of items, a savings score on the relearning trials of 40.2% is very reasonable. This compares with 52.88% found by Foulke and Morris (1961) using only 6 tactual patterns and association words from the New International Phonetic Alphabet. It is important that, in this study, the association words were more meaningful than the phonetic or nonsense words commonly used in paired-associate learning tasks. Most of the association features used in this study were familiar to the S's.

The differences in discriminability and associative value of the verbal terms are apparent from Figure 4. Differences in form, relief and size contribute to making a legible tactual symbol. In addition symbols can have informational properties which may aid recognition. Schiff, Kaufer and Mosak (1966) found that a tactual line, saw-tooth in cross-section, can be used to indicate direction, since it feels smooth in one direction and rough in the other. The 'tactual arrow' provided an 'intensity basis' for tactual perception. Point symbols on visual maps commonly specify direction, but when embossed, often seem inadequate to specify the same information for the visually handicapped.

Stimulated by Schiff's findings on the tactual arrow the authors utilized variation in height as a principle of symbol construction. Symbols 4 and 9 (steps) were adaptions of a symbol developed by Wiedel and Groves (1972) and consisted of units of increasing or decreasing height (see Fig. 1 for side elevations). These units specified 'up' or 'down'. In contrast to these symbols, similar information was specified in symbol 10 (road going uphill) and, although this symbol may have been masked by the linear symbols bounding it, the differences in the effectiveness of the multi-height versus single-height symbols as indicators of up or down are evident from Figure 4. Subjects feeling symbols 4 and 9 (steps) were able to run the pad of the finger down or up the symbol and, because of its distinctive informational properties often guessed that the symbol implied 'up' or 'down'. As a result of this finding a multi-height symbol will be used in the evaluation of mobility maps using gradient (road going up or downhill) as a navigational cue.

Symbols 4, 6 9 and 12 had particularly low percentage error (< 20%) for the learning trials, but on the relearning trials symbols 2, 4, 6, 9 and 11 had a very low percentage error rate (< 5%). Using a 10% error criterion of acceptability for the relearning trials, all symbols with the exception of symbol 3 (road with zebra crossing) would prove acceptable. Symbols 3 (road with zebra crossing) and 10 (road going uphill) had the highest percentage error of all the symbols tested and this can be partly explained by reference to Table 2. Both symbols were displayed in the context of two parallel lines which represented a road. Subjects found these two symbols difficult to distinguish. Therefore, it is probable that if one symbol was successfully altered the other would remain more legible. The substitution of a multi-height symbol for number 10 (gradient) has already been suggested. Symbols 2 (railway) and 7 (footpath) were relatively highly confused but this was mainly in the initial phase of the experiment and perceptual training might have been responsible for the lower percentage of errors in the relearning phase.

The shortcoming of evaluating tactual symbols in isolation as discrete stimuli is apparent when attempts are made to put these symbols together in a more complex display. Gêstalt psychologists support the idea that in perception the whole is more than the sum of the distinctive parts. Thomson (1968) summarises this as "the whole has properties of its own, so that the parts and relationships within the whole are largely a product of the entire configuration".

Table 3 shows that when the tactual symbols were displayed in a pseudomap subjects were able to obtain a high level of correct symbol identifications either with or without a key. However, instead of having the symbols presented to them the subjects had to search the entire configuration to find a particular symbol. Observations of the strategies adopted by the subjects confirmed recent analyses of tactual map reading strategies by Nolan and Morris (1971). One subject in this experiment noted the importance of 'full-scale coverage', but few applied any systematic search pattern. One would expect that children with higher IQ's would perform better than children with low IQ's on this task even without training. The lack of efficiency in search strategy used by subjects to locate symbols on the pseudomap caused some of them to give up their haphazard search even when they had a key. Failure to find symbols was particularly evident for subjects reading the lower right hand part of the map which was more isolated than other parts of the map (see Fig. 2). Symbol 4 (steps) was frequently missed completely or not detected as being distinct from symbol 7 (footpath).

Since the data shows no significant differences in correct identification of symbols for the matched groups, one using a key and another using memory alone, memorising a key of as many as 14 symbols may be a viable proposition. Constant reference to a key presents several problems:

(i) A key placed on the tactual map itself could be confused with part of the map.

(ii) Since two sheets (230 x 260mm) were required to present the key in this experiment, there is the problem of bulk of material.

(iii) Reading the key and then the map may be significantly more time consuming than referring straight to the map after memorising the necessary symbols.

It is hoped to examine these problems in a further experiment comparing the use of memory alone and key alone to locate symbols on a tactual pseudomap and to use dependent measures of time, errors and efficiency to compare both methods.

Most of the subjects showed a high degree of familiarity with the features and landmarks to be associated with the tactual symbols. Some of the younger children required some simplification of the terms involved; for instance, dual carriageway needed to be represented as 'two roads'. One subject began searching the central area of the pseudomap in order to find the symbol for 'north edge of the map' implying that he did not understand the concept involved. This subject, at least, had attached a verbal label to a symbol without realising the significance of that label. These observations confirm the necessity for development of rudimentary environmental concepts before or as part of a mobility programme utilizing tactual maps. Furthermore, development of these basic concepts would seem to be a prerequisite of meaningful use of tactual maps in any context (Franks and Baird, 1971; Franks and Nolan, 1971).

The majority of subjects tested on the pseudomap were able to plan and follow a simple route from the zebra crossing to the entrance of the building (see Fig. 2) indicating that they understood the significance and interrelationships of the tactual symbols they had learnt.

Appendix 1

Instructions for Sessions 1 and 2

There are 14 different raised map symbols I wish you to feel. Each raised symbol means something and you have to try and learn what these symbols mean.

Here is an example of a raised symbol which means a road (Present S with sample card).

I am now going to give you some more symbols but the meanings of the symbols are recorded on the tape-recorder and you will hear them 10 seconds after you feel the raised symbols. You have to try and give me the meaning of the symbol before the tape-recorder tells you. In other words, you have to beat the tape-recorder in giving your answer.

Try to remember the meaning of each symbol so that you can give the right answer before it is given by the tape-recorder.

(Repeat instructions and answer any questions)

(1st session only). You will not be able to give the answer to the meaning of the symbols until you have heard them once, so you can guess what they mean to begin with.

(After the 1st trial). You have now felt all 14 symbols. This time try to beat the tape-recorder with your answers, but remember that the symbols will not be in the same order as before.

Appendix 2

Instructions for Session 3

1. Find the north edge of the map.
   Turn the map so that it is at the top of the page.

2. Find the building with entrance.

3. Find the railway.

4. Find the crossroads with roundabout.

5. Find the steps going up.

6. Find the church.

7. Find the toilet.

8. Find the bus-stop.

9. Find the zebra crossing.

10. Find the dual carriageway.

11. Find the road going uphill.

12. Find the steps going down.

13. Find the crossroads with traffic lights.

14. Find the footpath.

15. Show how you would get from the zebra crossing to the entrance of the building.

Acknowledgements

The authors have carried out this work with the financial assistance of the Medical Research Council and the Science Research Council. The authors would like to thank Dr. J.D. Armstrong (B.M.R.U.), Prof. J.L. Douce (I.U.I.E.C.) and Dr. M.J. Tobin (R.C.E.V.H.). They would also like to thank the Headmaster and pupils of Lichey Grange School. Thanks are also due to Pauline James who prepared the tape recording.

References

Bentzen B.L. "An orientation and travel map for the visually handicapped: Hand production, testing and commercial reproduction".
Master's thesis, Boston College, 1971.

Berla' E.P. & Nolan C.Y. "Tactual maps: A problem analysis".
I.C.E.B.Y., Madrid, 1972.

Foulke E. & Morris J.E. "The learning and retention of associations between tactile stimuli and verbal responses".
Unpublished, American Printing House for the Blind, 1961.

Franks F.L. & Baird R.M. "Geographical concepts and the visually handicapped".
Exceptional Children, Vol. 38, No. 4, Dec. 1971, pp 321-324.

Franks F.L. & Nolan C.Y. "Development of geographical concepts in blind children".
Education of the Visually Handicapped, Vol. 2, 1970, pp 1-8.

Gill J.M. "Computer production of tactile diagrams and maps".
The Leonard Conference, Cambridge, England, Jan. 1972, pp 73-77.

Gill J.M. & James G.A. "A study on the discriminability of tactual point symbols".
Research Bulletin, to be published.

James G.A. "Problems in the standardisation of design and symbolisation in tactile route maps for the blind".
New Beacon, Vol. 56, No. 660, April 1972, pp 87-91.

James G.A. & Gill J.M. "A pilot study on the discriminability of tactile areal and line symbols for the blind". Research Bulletin, to be published.

James G.A., Armstrong J.D. & Campbell D.W. "Verbal instructions used by mobility teachers to give navigational directions to their clients". New Beacon, Vol. 56, No. 672, May 1973, pp 86-91.

Leonard J.A. & Newman R.C. "Three types of maps for blind travel". Ergonomics, Vol. 13, No. 2, March 1970, pp 165-179.

Morris J.E. & Foulke E. "The learning and retention of associations between pairs of tactual and auditory stimuli". Unpublished, American Printing House for the Blind, 1960.

Nolan C.Y. & Morris J.E. "Tactual symbols for the blind: Final report". American Printing House for the Blind, 1963, OVR-RD-587.

Nolan C.Y. & Morris J.E. "Improvement of tactual symbols for blind children". Report of Department of Health, Education, and Welfare. Project No. 5-0421, 1971.

Siegel S. "Nonparametric statistics for the behavioural sciences". New York: McGraw Hill, 1956.

Schiff W., Kaufer L. & Mosak S. "Informative tactile stimuli in the perception of direction".
Perceptual and Motor Skills, Vol. 23 (Monogr. Suppl. 7), 1966.

Thomson R. "History of psychology".
Pelican, 1968.

Wiedel J.W. & Groves P.A. "Tactual mapping: Design, reproduction, reading and interpretation".
University of Maryland, Occasional Papers in Geography No. 2, 1972.

Williams M. "Williams intelligence test for children with defective vision".
University of Birmingham, England, 1956.